AGRICULTURAL

Science Review

THE UNIVERSITY OF MICHIGAN
JUL 31 1969
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COOPERATIVE STATE RESEARCH SERVICE U.S. DEPARTMENT OF AGRICULTURE VOL. 7, NO. 1

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INTEGRATED
CONTROL OF INSECTS
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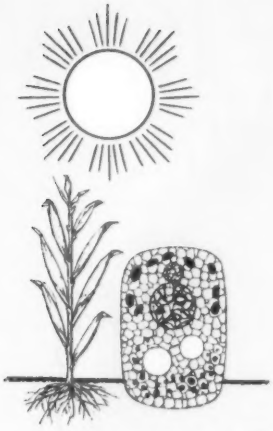

AGRICULTURAL SCIENCE REVIEW

First Quarter 1969 Vol. 7 No. 1

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Ants, Spiders, and Bees

Most new developments and breakthroughs in the world of science generally have roots in past accomplishments of other scientists. Even though we like to think that a rare, new idea may be a distinct product of our own times, the roots are often there if we dig deep enough.

This principle most surely applies to the concept of integrated control of insects—despite the fact that the term cropped up only about a decade ago.

Actually, Francis Bacon alluded to the concept over 300 years ago, although he used other terminology to describe it and probably never dreamed that man would have to wage war against insects. Yet the allusion is there:

"Those who have handled sciences have been either men of experiment or men of dogmas. The men of experiment are like the ant; they only collect and use; the reasoners resemble spiders, who make cobwebs out of their own substance. But the bee takes a middle course; it gathers its material from the flowers of the garden and of the field, but transforms and digests it by a power of its own. . . . Therefore from a closer and purer league between these two faculties, the experimental and the rational (such as has never yet been made), much may be hoped."

The essence of this quote—a closer and purer league between two faculties—epitomizes what's going on in integrated control: a union among several disciplines in an effort to maintain a reasonable balance in the scheme of Nature.

Can we glean a deeper message from Bacon's beautiful symbolism? In man's relentless search for intelligibility, can he continue to learn something from the lesser creatures around him—the ants, spiders, and bees? Perhaps what we really mean when we say that integrated control appears sound is that we have discovered in it the likeness of another process which we already know will work.—W. W. K.

AGRICULTURAL SCIENCE REVIEW is published quarterly by the Cooperative State Research Service, U.S Department of Agriculture, Washington, D.C. 20250.

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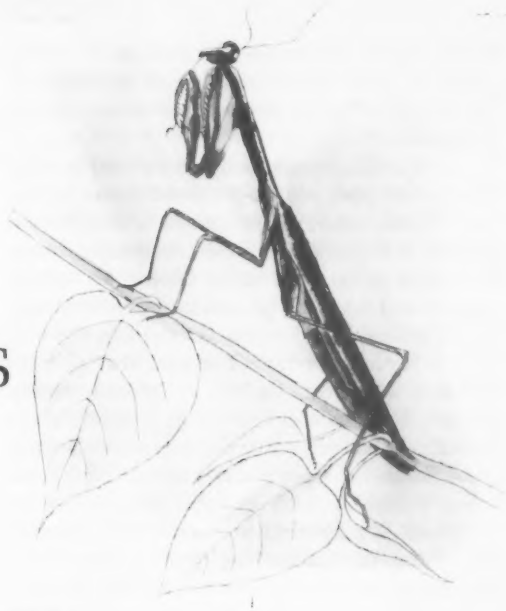
INTEGRATED CONTROL OF INSECTS
A Challenge for Scientists



RAY F. SMITH

INTEGRATED control is an ecological approach to the control of harmful pests. It derives its uniqueness from emphasis on the fullest practical utilization of existing mortality and suppressive factors in the environment. Its strategy is one of "management or containment" rather than "seek and destroy." The goal of an integrated control system is to provide a stable and economically sound procedure for crop protection.

Research requirements for an integrated control approach; that is, a management strategy, are not fundamentally different from a seek-and-destroy strategy. In both cases, the greatest effectiveness can be achieved with detailed information on the ecological elements of the agro-ecosystem and the population ecology of the pest species. This, in broad terms, delineates the areas of research needs for integrated control.

Agro-Ecosystems

THE term, agro-ecosystem, refers to a unit composed of the total complex of organisms in a crop area together with the overall conditioning environment and as further modified by the various agricultural, industrial, recreational, and social activities of man. Thus, agro-ecosystems are a part of the man-altered landscape modified and controlled for the production of agricultural and forest crops. Man and his civilization are dependent upon reaping a harvest from these systems.

Integrated control, developed in the context of the agro-ecosystem, does not necessarily have as its goal the preservation and maintenance of the system without change. Rather, the goal of integrated control is the manipulation of the agro-ecosystem to hold pests below economic levels and to avoid disruption of the system with its ensuing consequences.

Any modification of the agro-ecosystem has the potential to change the crop plant and the crop environment and hence the attractiveness and suitability of the plant or environment to pests. These manipulations can provide powerful tools for integrated control. Integrated control specialists must use imagination and intuition to select those things that can produce the desired effect. Among the important cultural controls that might be considered are modified planting and harvesting date, crop-free periods, uniform planting dates for entire areas, destruction of alternate host plants, destruction of crop residues, improved plant varieties, etc.

Within this context, therefore, it should be clear that all aspects of the agro-ecosystem must be considered simultaneously in the development of sound crop protection.

The fact that crop monocultures are often severely damaged by pests while the diverse climax vegetation of many natural environments is little harmed has lead to the assumption that maximum diversity is desirable in agro-ecosystems. Diversity is another research tool that may be used in the environment, but we must approach environmental diversity with caution because we cannot assume that diversity inherently will create stability in the environment. In the present state of knowledge, it is difficult to generalize. Sometimes diversity of plant species and age structure decreases pest damage; in other cases, it may increase it. Each agro-ecosystem needs to be considered as a distinct man-manipulated system in which integrated control may involve elimination of undesirable elements of diversity as well as maintenance or establishment of desirable elements. In other words, the right kind of diversity must be established, and we can only know what the right kind of diversity is by ecological studies of the environment.

Integrated control programs require a high level of scientific competence. However, the first steps toward integrated control can be made in the early phases of the development of this information. Usually there must at least be a minimum level of information on the following points: (*a*) the general biology, distribution, host range and behavior of the pest species; (*b*) an approximation of the pest population levels that can be tolerated without significant crop loss; (*c*) a rough evaluation of the times and places of occurrence of the significant predators, parasites, and pathogens and the factors limiting their effectiveness; and (*d*) information on both abiotic and biotic causes of mortality in the several stages and all the annual generations of the pest species.

In many circumstances, there is a distinct ecological advantage in maintaining minimum or subeconomic numbers of the pest species, rather than to seek entire elimination of them from the particular area. In some circumstances, it may also be practical and realistic to introduce significant numbers of the pest at critical times so that the regulating system may be maintained and not disorganized. When populations of the pests are locally eliminated or become very scarce at a critical time for their natural enemies, a resurgence of the pests is likely at a later time. The value of long term benefits resulting from preservation of the regulating forces must be weighed against the hazard of the required pest numbers. Then also, there is a possibility that in some cases, elimination of the pest may permit another pest to come in, one that is more difficult to control. In any case, our best strategy must be based on sound ecological research.

The Cañete Valley Story

A CLASSIC example of what can happen when a pest control program ignores ecology and relies on unilateral use of chemical pesticides is that of the Cañete Valley (Peru) story. Here, during the pre-DDT regime, chemical control of pests of ratoon cotton (second and third year cotton) was based mainly on arsenicals and nicotine sulphate. During 1943–48 the average annual yield was about 470 lbs/acre. Because of a heavy *Heliothis* and aphid outbreak in 1949, the average yield dropped to 326 lbs/acre.

From 1949 to 1956, growers relied heavily on the new exciting organic insecticides such as DDT, BHC, and toxaphene. Some cultural practices were modified to increase yields. New strains of *Tanguis* cotton were introduced and more efficient irrigation was practiced.

At first these procedures were very successful. Cotton yields nearly doubled. Farmers were enthusiastic and got the idea that the more pesticide they used the better the crop would be. Insecticides were applied like a blanket over the entire valley. Trees were cut down to make it easier for airplanes to treat the fields.

But then things began to happen. Birds that had nested in the trees disappeared, along with insect predators and parasites. One by one the new chemicals became ineffective as resistance developed. Finally, as insects became rampant in the cotton fields, the 1955–56 season was an economic disaster. In desperation, growers appealed to their local experiment station for help. With the help of the Ministry of Agriculture, a new, integrated control program was set up, and within a season or two the situation vastly improved. Today, cotton yields in the Cañete Valley are the highest in its history, averaging more than 700 lbs/acre.

Some Critical Factors

ALMOST any aspect of an agro-ecosystem can significantly influence the pest complex—and ultimately plant damage and crop losses. Changes in any one aspect can cause far-reaching changes in others. This interrelationship increases the complexity and scope of the research problems in integrated control. Only the more critical ones are discussed here.

Threshold Levels.—To achieve any measure of success in an integrated control program, one must determine in each case a threshold level of the pest population below which any control operations would be unwarranted economically, and often even harmful. Establishment of sound economic injury thresholds is not easy, and will require the combined talents of both pest control specialists and agricultural economists. Initially in an integrated control system, the determination of economic entry thresholds can be generally based on empirical evidence—that is, past experience with the pests. Later, however, these levels should be constantly reviewed and retested in accordance with changes in farming practice and, as additional information is obtained, from further observations and from carefully controlled experiments.

An entomolgist friend recently commented that he could not be concerned with the economic aspects of a pest problem he was attempting to solve. He felt that he was not qualified to consider these economic aspects. But I maintain that the economist is not prepared to handle entomological aspects, and that the economic and entomological aspects must be considered together. The answer will come from broadening horizons for both entomologists and economists and cooperation between them.

Natural Enemies.—We cannot assume that the mere presence of natural enemies indicates that they are important. Careful studies must be made to assess their role in the regulation of the pest population and also to provide ways in which they may be supplemented by mass release of additional parasites or other control measures, such as cultural controls and chemical controls at critical times in the development of the population of pests and the natural enemies. Again, ecological research is the basis upon which any adjustments can be made.

It is widely recognized that only a small percentage of the eggs deposited by bollworm moths develop into the damaging late instar larvae. Considerable mortality is known to be from natural causes. Although available data on the mortality of eggs and small larvae are more suggestive than conclusive, apparently many of the deaths are caused by insect predators. Research at the Arkansas Experiment Station showed that as much as 41 percent of cotton bollworm eggs were destroyed by predators within 24 hours after deposition.

Most other insect pests of cotton likewise have important natural mortality agents. Cotton leaf perforator larvae, for example, are heavily attacked by predators, but there are several important parasites as well. About 70 to 80 percent of the larvae in the leafmining stage are killed by parasites and almost as many are killed by other parasite species in the final stage. Unfortunately not all pests of cotton are subject continually to such satisfactory and desirable population regulation by beneficial insects. Parasitism and predation of the boll weevil, for example, is far less than adequate, and natural enemies of the pink bollworm are also limited.

We need improved techniques for measuring the mortality caused by predators and pathogens in order to evaluate their importance in integrated control systems. In many agro-ecosystems, mortality of natural enemies can be modified or reduced by adjustments to the agro-ecosystem. This modification may be done by providing supplemental foods or alternate hosts or by manipulating pesticides so that they cause the least harm to the natural enemies. The seasonal sequence of essential host plants of pests must be established for polyphagous pest species. This information will provide a potential control procedure if the crop sequence can be changed to the detriment of the pest. Although it is not always essential, a good system of pest surveillance and protection is often very useful in development of an integrated control system.

Biological Knowledge.—Certain critical items needed for sophisticated pest control are often missing. These include details of absolute population size and dispersion, flight range and other aspects of vagility, seasonal abundance—especially at those times of the year when the pest populations are lowest—and mating behavior and the factors that modify it. The value of partial control in preference to full control in some circumstances can also be revealed by ecological studies. Each alternative

situation and the attendant implications must be carefully evaluated.

Crop Susceptibility.—Just after World War II, the California Experiment Station introduced the new strawberry varieties *Lassen* and *Shasta*. These varieties had been selected for large fruit size, shipping quality, and yield. Strawberry acreage increased rapidly, and an industry valued at over $40 million annually developed in California. The greatly increased acreage permitted easy spread from field to field of the cyclamen mite, *Steneotarsonemus pallidus*. The new varieties were very susceptible to damage by this mite and a serious pest problem had developed from the varietal change. Widespread use of endosulfan then reduced the cyclamen mite populations to low levels. At the same time a reduction in the duration of the strawberry plantings from 3 to 4 years down to 1 or 2, together with the influence of predaceous *Typhlodromus* mites, helped to keep the cyclamen mite populations low. Because of the low populations, there is little spread to new strawberry fields and the cyclamen mite has returned to insignificant pest status. The varieties are still susceptible but endosulfan treatments are needed only occasionally.

The above example is one in which the crop plant was changed. The pests also can change. In the past, a phloem-feeding leafhopper, *Empoasca solana*, developed enormous populations in the Imperial Valley of California but only on sugar beets. After many years of virtual host specificity, this leafhopper moved to cotton fields in vast numbers—but only when the sugar beets were harvested or when the sugarbeet plants became unattractive to the pest just prior to harvest. A few years later the leafhopper began to reproduce on cotton early in the growing season when the sugarbeet plantings were still attractive to the species. Although sugar beets are still considered to be the preferred host and also provide the major overwintering site, this leafhopper provides an elegant example of adaptation to a new host plant and a significant pest relationship between crops.

Considerable attention should be given to those characteristics of plants that allow or disallow insects to become pests. Very little experimentation has been devoted to this aspect in integrated control systems, although resistant alfalfa varieties are part of the integrated control system for the spotted alfalfa aphid. As resistant plant varieties do become available, there is usually little difficulty in integrating them into the control system. With the integrated control approach, the plant breeder need not seek the "perfectly resistant" plant variety; but "partial resistance" in combination with protected natural mortality factors may provide adequate economic control.

Differential Toxicity.—If agricultural chemicals are to be used in a harmonious manner in the agroecosystem, then we must find materials that are inherently selective or which can be used selectively. All pesticides have some selectivity, but the range and degree of selectivity is substantial. Much effort has been expended in seeking materials with a relatively high toxicity to invertebrates and low toxicity to mammals. This is of course necessary, but we must also seek differential toxicity within the Phylum Arthropoda. We do not need the ultimate specificity which would permit us to prescribe a specific chemical for each pest species. However, we do need effective materials that are specific for groups of pests, such as aphids, locusts, lepidopterous larvae, weevils and muscoid flies. There are now some indications that the chemical industry can produce such materials on an economically feasible basis.

There are many situations where the pest abundance/crop damage relationship is such that we do not need to have high percentage mortality. Instead of seeking 95 percent mortality or higher, we may be satisfied or even more content with a kill of 75 percent or even much lower. Under such circumstances, the dosage of pesticide needed for the low percent mortality permits the desired selective action.

Integrated control of the spotted alfalfa aphid in California is a typical example of differential kill. Economic thresholds were established so that insecticides are applied only when damage is imminent. Native predators, introduced parasites, and entomogenous fungi now keep the spotted-alfalfa-aphid populations below the economic threshold for most of the year. When population counts in the individual field clearly demonstrate that a field is threatened, Systox is applied at low dosages. These chemical treatments give adequate control, but do not necessarily eradicate the aphids. Most of the predators and parasites survive and persist on the remaining aphids.

I suspect that screening procedures for new pesti-

cides have bypassed many compounds with great potential value for crop protection, because of the emphasis on high percentages of mortality. The development of new, highly specific pesticides will undoubtedly come very slowly. In the meantime, we have to make the best use of chemicals now available. In this regard, we have not fully utilized the selectivity available by the modification of dosages, formulations, times of applications, method of application and other techniques. Over the years, economic entomologists have developed a wide array of procedures to increase the percent mortality to the target pest species. The same techniques should now be explored to provide a differential mortality between the target pests and non-target organisms. We do not need perfect selectivity—an all or none situation. Rather, it is more desirable to have a differential kill that leaves the balance in favor of the beneficial forms.

Social Implications

ANOTHER aspect of pest control action that must be considered in developing integrated control systems is the broad social implications of controls and decisions—particularly in actions involving multiple use of the land. An ill-considered action against one target pest may destroy or greatly modify other resources associated with that same land. Modern holistic approaches in ecology have now reached a stage where they can be used effectively to understand and analyze insect problems. In many situations, alternative control procedures can be selected, and we must choose between the positive and negative values of an action or group of actions.

The production of cotton in Central America illustrates this point very well. After a recent visit to the cotton producing areas of Central America, it is my opinion that insect pest control there is just one or two growing seasons away from a situation such as affected the Cañete Valley of Peru in 1956. The bollworms, *Heliothis zea* and *H. virescens*, have now replaced the boll weevil as the most important pests and show increasing evidence of resistance to the available pesticides. An array of formerly minor pests has been raised to major status. Included are several species of *Spodoptera, Alabama argillacea, Trichoplusia ni, Aphis gossypii* and *Bemisia tabaci*. Dosages and numbers of applications of pesticides have been increasing steadily and control is becoming poorer. The possibilities of a cotton crop failure are very great in the next year or two if current practices are not modified. When one considers that over 40 percent of the export dollars for Nicaragua comes from the sale of cotton fiber, the possible social and political implications are quite disturbing.

Our decisions are difficult ones to make. The real dilemma lies in the complexity of our environment, the subtle, varied, and multiple implications of specific actions and the conflicts of interest and opinion as to what is important and what is desirable. In many situations, a short-run view indicates that resources should be allocated to create higher productivity so that more people may be fed. But in the long run, other values such as the quality of human existence and the stability of production should be considered.

The farmer's or producer's determination as to what should be done may consciously or intuitively—on good or bad advice—be influenced by such elements as available technology for crop protection, cost of avoiding the potential loss, working conditions, the ultimate use of the crop and other benefit-related factors. The crop production specialist must fully understand the whole gamut of of economic factors and mesh them with an understanding of the ecology of the pest species and their natural enemies.

To develop these kinds of information and to organize all elements into coordinated control systems requires the talents of highly trained specialists. At the same time, these specialists require the assistance and back-up information of systematists, ecologists, behaviorists, physiologists, morphologists, geneticists, and others working on the fundamental aspects of their fields.

The use of land is an ecological operation. Although man's concept of the land and its uses may be modified by religious or political beliefs, it is still fundamentally an ecological relationship involving man and his evnrionment. Hence, we should turn to ecological research for assistance. Scientific pest control has always required a knowledge of ecological principles, especially of the natural factors regulating the pest population. If we are to maintain stable pest control systems—and especially with the introduction of new and more sophisticated technologies of pest control—it will be necessary more than ever to give full accord and support to the ecological aspects of pest control.

New Uses for Reverse Osmosis

A MAJOR economic factor in conventional methods for the production of maple syrup is the cost of fuel. In order to obtain one gallon of syrup, water must be removed by heating processes from 30 gallons of sap.

Chemical engineers at the National Research Council of Canada have undertaken a research project to determine whether these high fuel costs can be reduced substantially with a process known as reverse osmosis. If this method proves practical, it will represent a major saving for tree farm operators in Eastern Canada whose production last year amounted to more than 2.7 million gallons of maple syrup valued at about $11.5 million.

W. S. Peterson of the Chemical Engineering Section of NRC's Division of Applied Chemistry is currently experimenting with maple sap using a reverse osmosis cell. With this arranagement, heating costs per gallon have been reduced from approximately 50 cents to 5 cents.

Reverse osmosis is a technique originally developed to purify sea water. In principle, it can be used to separate any substance in liquid or gaseous solution. Essentially, it involves the use of a porous membrane whose chemical nature can be made so that it has a preferential attraction for the solvent and a similar repulsion for the solute in a solution.

In Peterson's experiments, sap under 1,500 pounds pressure was forced past the surface of the membrane held inside a stainless steel pressure chamber. Water is forced preferentially by pressure through holes measuring about a few hundred millionths of a centimeter in diameter. The chamber has two separate outlets—one for the water and the other for the concentrated sap of syrup.

By this method, 75 to 90 percent of the water is removed from the tree sap. The remainder must still be boiled away since maple sugar producers have found that the maple syrup flavor is imparted through the boiling process.

Although the heating costs can be reduced 10-fold by using present reverse osmosis technology, the process is still not economical for use by small-scale syrup producers, according to Peterson.

While the membrane itself can be purchased for as little as 20 cents per square foot, the cost of the membrane in a spiral module form—the form most favored in the sample sap industry—runs about $5 a square foot. A major processor has estimated that this cost of fabrication would have to drop to about $1 a square foot in order to make reverse osmosis economical to use with maple sap.

In his experiment, Peterson uses the Loeb-Sourirajan type of porous cellulose acetate membrane, developed from the pioneering work of Srinivasa Sourirajan of the Chemical Engineering Section, NRC.

Sourirajan foresees a wide variety of uses for the process: desalination, water pollution control, water renovation, water purification, waste reclamation, concentration of aqueous sugar solutions, and separation of liquid hydrocarbon mixtures.

Although Canada may not have any pressing need for desalinating plants, it does have water pollution problems, notably with the Great Lakes and rivers that flow through metropolitan areas. It is here that the reverse osmosis process will eventually have one of its greatest impacts.

Pretreatment of water for the removal of excess pollutants such as nitrates, fluorides, chlorides and others may be necessary in many water supply systems. By the appropriate choice of the porosity of the membrane, practically any degree of solute separation can be obtained, according to Sourirajan. He believes the data compiled in the work with the reverse osmosis process are significant enough for consideration by industry.

Experiments with samples of raw sewage water, obtained from the city of Ottawa's primary sewage treatment plant, indicated that reverse osmosis was capable of offering an effective and economical means of upgrading sewage water to a quality suitable for almost all water uses.

Present primary and secondary sewage treatment facilities have as their objective the removal of organic material and suspended solids. These treatments are not designed to remove nitrates, phosphates or the nonbiodegradable surface active agents (e.g. detergents). The removal of the latter would be the objective of tertiary sewage treatment facilities not in extensive use today.

Sourirajan believes reverse osmosis can effectively take the place of tertiary and, in some cases, of tertiary and secondary treatment facilities.

From: *Science Dimension*
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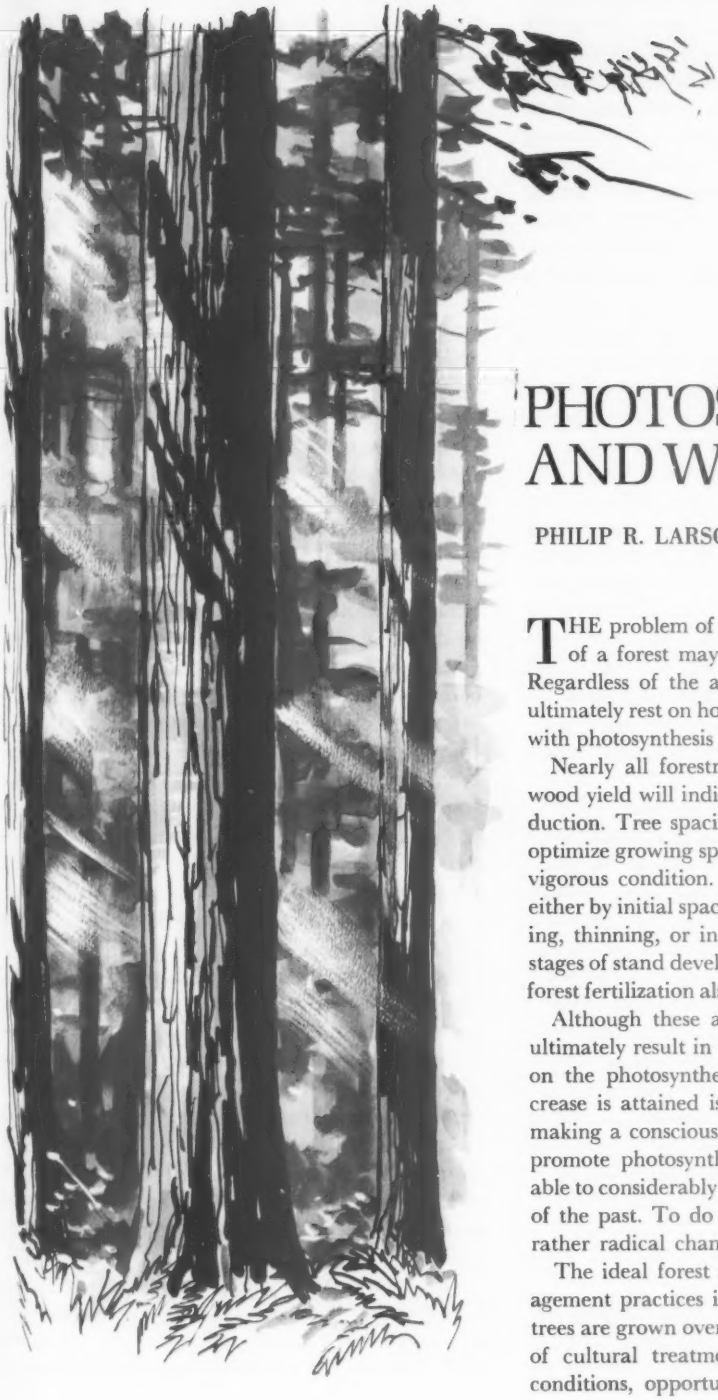

PHOTOSYNTHESIS AND WOOD YIELD

PHILIP R. LARSON AND JOHN C. GORDON

THE problem of increasing the yield of a tree or of a forest may be approached in many ways. Regardless of the approach, however, success will ultimately rest on how much the processes associated with photosynthesis are favored.

Nearly all forestry practices aimed at increased wood yield will indirectly favor photosynthetic production. Tree spacing, for example, is adjusted to optimize growing space and to maintain crowns in a vigorous condition. This adjustment can be made either by initial spacing at planting time or by weeding, thinning, or intermediate cutting during later stages of stand development. The current practice of forest fertilization also promotes crown development.

Although these and other silvicultural practices ultimately result in increased wood yield, any effect on the photosynthetic processes by which the increase is attained is usually taken for granted. By making a conscious and more determined effort to promote photosynthetic production, we should be able to considerably improve the indirect approaches of the past. To do so, however, may require some rather radical changes in our concepts of forestry.

The ideal forest resulting from traditional management practices is an imitation of nature. Large trees are grown over long rotations with a minimum of cultural treatment. Under these management conditions, opportunities for direct application of

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basic research results and for manipulation of tree growth in a desired direction are severely hampered. Although forest productivity has increased in some areas where intensified silvicultural practices have been used, the gains have been largely attained by trial and error. The real breakthrough in increasing wood yield will come only when our present knowledge of tree growth is used to develop new imaginative forestry practices and silvicultural systems. These new systems must remain sufficiently flexible to provide a continuous flow of information between research and practice.

The deliberate manipulation of photosynthesis, respiration, and related processes is the most rational biological approach to the increase of wood yield. The aim of this approach would be not only to increase photosynthetic production and decrease respiratory losses, but also to divert a larger proportion of this production into a useable form of wood. Before such a program could be undertaken, considerable basic information would be required. One initial requirement would be detailed knowledge of the production, distribution, and utilization of photosynthates within the tree. These processes present well-defined trends or patterns that vary both seasonally and perenially. If we are to determine where manipulation to increase wood yield might begin, it is necessary that we clearly understand these patterns.

The seasonal course of development of young red pine and cottonwood trees, typical conifer and hardwood species respectively, illustrates these patterns very well. Because these two species present contrasting developmental histories, different parameters determine the availability of photosynthate for wood formation during the growing season. Thus, in young red pines, availability is determined by seasonal changes in (*a*) the total quantity of needles, and (*b*) the relative photosynthetic activity and position of the different age classes of needles. In young cottonwoods, availability is determined by (*a*) stem position, (*b*) relative photosynthetic activity, and (*c*) rates of maturation and senescence of individual leaves.

Red Pine (Pinus resinosa Ait.)

A YOUNG red pine several years old that has received adequate cold-exposure through the winter will begin growth when spring temperatures remain at favorable levels. The energy requirements for the awakening process are provided by reserve foods and this may, in fact, be one of the primary uses of reserve foods in conifers. Old needles, formed during previous seasons, also rely on stored foods as a post-dormancy energy source. Thereafter, they quickly reach a positive level of photosynthetic production as spring growing conditions improve.

Most of the early-season photosynthate is translocated to the roots, since root growth of red pine precedes bud expansion under normal conditions of soil warming. As the buds begin to elongate, photosynthetic production of the old needles increases, and translocation of photosynthates shifts from the roots to the new growth center at the apex. While shoot extension growth is in progress, elongation of the new needles of red pine, as in most pine species, is partially suppressed. The beginning of vigorous needle elongation occurs when shoot extension is about 90 percent complete, and this point marks an important transition in the seasonal development of young red pines. This transition period coincides with the maximum photosynthetic efficiency of needles of the previous season and the maximum export of photosynthates from these needles to the new shoot. The surge of growth by the newly elongating needles together with their high respiratory activity diverts translocation away from the lower stem and roots. Import of photosynthate by the shoot is primarily at the expense of the roots; export to the roots at this stage of development is at a minimum. The newly elongating needles are not entirely parasitic on the older needles, since they do contribute some photosynthate to their own development.

As the new needles continue vigorous elongation, they become increasingly self-sufficient; their photosynthetic efficiency increases, and they retain most of their photosynthetic production and incorporate it into structural tissue. The increasing independence of the new needles is accompanied by gradual changes in the distribution of photosynthate originating in the old needles. Export to the roots again increases and the first indications of the seasonal decline in photosynthetic efficiency of the old needle appear.

The stem is very active throughout the entire period of new shoot development. Cambial activity begins with the bursting of the buds. In young red pine, most of the earlywood in older stem inter-

nodes is produced during shoot extension and the early stages of needle elongation. Surprisingly, however, the new needles contribute practically nothing to radial stem growth at this time. Thus, export from the old needles maintains not only extension growth of the current-year internode, but also the early-wood phase of radial stem enlargement of all internodes.

From the standpoint of wood yield and productivity, the developmental stage of greatest interest occurs when the new needles approach the end of their elongation growth. This growth phase has been more appropriately referred to as "new needle maturity," for its signifies a metabolic state rather than simple cessation of needle elongation. Metabolic changes in the new needles evidently trigger very pronounced changes throughout the tree. Not only do the new needles reach their peak of photosynthetic efficiency at this time, but they become exporters of large quantities of photosynthate. Coincident with these changes in the new needles is an almost complete reversal of translocation from the old needles. Very little photosynthate is exported upward to the new shoot, and translocation is now almost exclusively downward as a new surge goes to the roots from needles of all ages. Elimination of new needles as a metabolic sink for photosynthates from the old needles—together with increased availability of photosynthate from new needles—also provides an increased supply for the developing xylem tracheids. This increased supply of photosynthate following new needle maturity has been correlated with the pronounced increase in secondary wall thickening of the tracheids associated with latewood development.

In the post-maturity phase near the season's end, distribution of photosynthate is again segregated according to age class and position of the needles on the stem. The current-year needles preferentially contribute to the bud and to wood formation in the upper-stem internodes, whereas the older needles contribute principally to wood formation of the low-

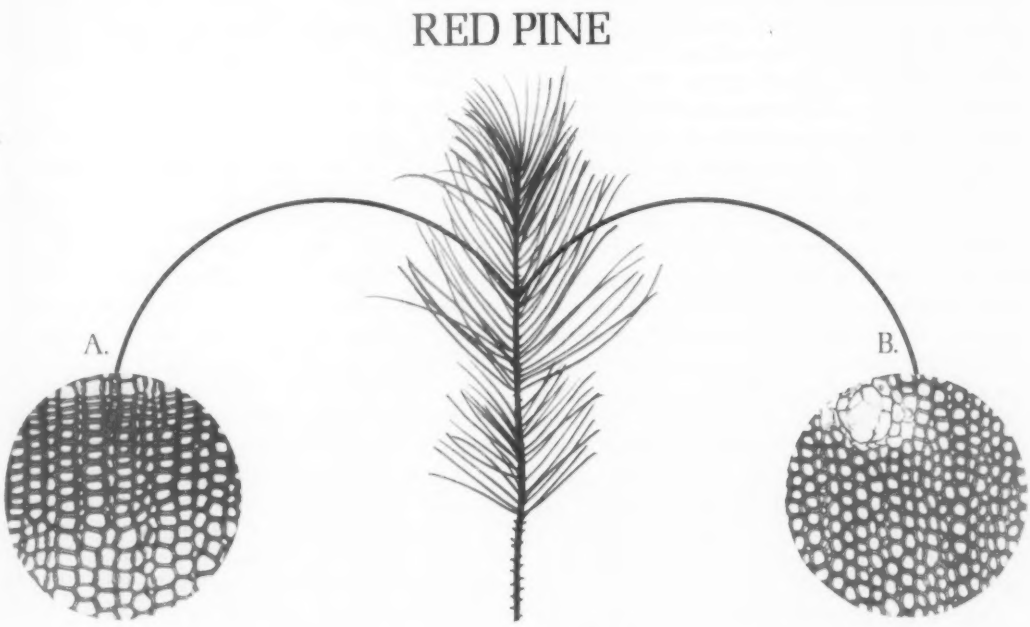


FIGURE 1.—*Red pine photomicrograph.* (*A*) A growth ring consisting of large-diameter earlywood tracheids and narrow-diameter latewood tracheids is produced by young red pines during normal seasonal development. (*B*) Latewood tracheids with extremely thick walls can be produced by maintaining photosynthesis at a high level during an artificially prolonged growing season.

er-stem internodes. All needles translocate large quantities of photosynthate to the roots at this season, and reserve carbohydrates are deposited in storage tissues throughout the tree.

Knowledge of these seasonal patterns of growth and development provides a starting point for determining how cultural or genetic manipulation might improve wood yield. Examination of the patterns reveals that wood formation is closely correlated with development of the new shoot, particularly with growth of the new needles. Consequently, to increase wood yield, we must first take advantage of those factors that influence needle growth. From previous work we know that the earlywood part of the growth ring in the stem is formed during shoot extension and the early stages of needle elongation. Latewood initiation occurs shortly after bud set and usually coincides with new needle maturity. Transition to latewood may vary, however, with the vigor and developmental state of the new shoot. Although wood formation occurs throughout most of the growing season, the stem cambium must nevertheless compete with the primary growth centers of the shoot and root for available photosynthates. However, since this competition follows a fairly well-defined seasonal pattern, the many possibilities open to us for manipulating that part of the growth cycle associated with photosynthesis and wood yield can all be reduced to two main options. The first coincides with earlywood formation; the second with latewood formation on the stem.

Earlywood is produced from photosynthate not required for shoot or root development. To produce more earlywood, the first option is to direct more photosynthate into the stem without curtailing overall photosynthetic production. That is to say, we must optimize foliage production and photosynthetic capacity while minimizing that part of the crown which is least efficient. Silviculturally, this is known as crown control. By manipulating crown shape and structure, including needle length and density, it is possible to achieve an optimum balance between the production of new photosynthetic surface and earlywood formation on the stem.

Latewood is primarily produced following new needle maturity. Therefore, the second option is to prolong photosynthetic production at a maximum level during that stage of development when a high proportion of the available photosynthate is normally directed to the stem. Many of our coniferous species, such as red pine, do not fully utilize the growing season. Even though photosynthesis continues until late summer and fall, the cambium becomes dormant and wood formation ceases much earlier. There are undoubtedly many situations where photosynthesis of the tree falls well below its potential because of lack of demand for additional assimilates during late summer. By judicious selection, breeding, and silviculture it may be possible to significantly prolong the period of wood formation without reducing winter hardiness.

Cottonwood (Populus deltoides Marsh.)

COTTONWOOD is typical of hardwood species with an indeterminate meristem. It continues to produce new leaves over an extended, but not an indefinite, period as long as growth conditions remain favorable. Because of this growth habit, there is a repetitive pattern of leaf development. Thus, each new leaf passes through a developmental sequence similar to that of previous leaves. But, because of increasing tree size and position of the leaf on the tree, gradual changes do occur. Under well-defined conditions of growth, these changes are predictable.

In a young cottonwood with only a few fully expanded leaves, each new leaf that appears is critical for seedling survival, and it expands rapidly and matures quickly. The photosynthate exported by this newly mature leaf is bidirectionally distributed; a rather high proportion goes to the roots as well as to the shoot. These first leaves are short-lived; they senesce early and abscise as they are functionally replaced by other leaves. As new leaves are added acropetally on the stem, gradual changes occur in leaf development, photosynthetic efficiency, and translocation patterns.

A new leaf developing from the apex is at first totally dependent on the exporting leaves beneath it. The bulk of its import goes into structural tissue, but its respiratory metabolism is also high. Photosynthesis in a new leaf begins early, and its initial production will be used almost entirely for its own growth and metabolism. Although some export may begin when the leaf reaches half size, it does not become a major exporter until it approaches full development. Maximum export occurs when the leaf is fully mature. At this time, phostosynthetic

efficiency reaches a peak and metabolic consumption of photosynthates within the leaf is minimal.

Translocation from a newly exporting leaf is predominantly upward, until the newer leaf above assumes this role of serving the apex. Then the trend shifts to bidirectional, and eventually translocation becomes exclusively downward. Thus, the translocation of photosynthate from the stem leaves on a young cottonwood exhibit a continuum; the upper most leaves supply the apex, the lowermost leaves supply the lower stem and roots, and that from the intermediate leaves travels bidirectionally. The preferential direction of translocation from any one leaf on the stem will depend on the relative position of the consuming organs and their demands for photosynthate.

As implied earlier, the yield potential of an individual leaf changes according to the size of the young tree and the position of the leaf on the stem. With increasing plant size from the seedling stage, leaf size increases to a maximum that varies with growth conditions. Larger leaves require longer developmental time. As the number of developing leaves on the shoot increases, more exporting leaves are required to supply photosynthate to them. However, once these larger leaves reach the exporting stage, their photosynthetic production is extremely high and their respiratory requirements are low. Furthermore, these highly efficient leaves on young trees beyond the seedling stage are long-lived and they continue exporting photosynthate for many weeks.

A minimum of structural tissue is produced in the region of the shoot where leaf expension occurs. Most of the structural elements in the upper shoot are confined to the essential vascular, pith, and cortical tissues. However, as soon as a leaf approaches maturity and begins exporting photosynthate, the cambium of the stem internode to which it is attached begins more vigorous activity. Although a leaf preferentially feeds the internode to which it is attached, a basipetal gradient exists, and one leaf may contribute to many internodes beneath it. The cumulative contribution of all exporting leaves to the stem cambial zone is consequently large, and the developing wood uses much of the available photosynthate. This proportion increases progressively with tree size.

Although the developmental patterns for cottonwood are quite different from those of red pine, there are similarities in the ways that growth may be manipulated to increase wood yield. The primary meristems of the shoot and root take precedence over the stem cambium. So it is necessary to increase photosynthesis and at the same time increase that proportion of available photosynthate directed to the stem. This may be done by manipulating crown shape and structure, leaf display, or photosynthetic efficiency.

Since vessel formation in cottonwood is related to new leaf development, the fiber/vessel ratio of the wood is also amenable to manipulation. Genetic selection or cultural measures either to prolong photosynthetic production or to delay senescence of individual leaves would have a two-fold effect: (1) Increase photosynthate available for stem growth, and (2) increase the fiber/vessel ratio, hence, the total amount of useable wood substance.

Initiating a Program for Increasing Wood Yield

THE patterns of seasonal development described for red pine and cottonwood reveal a wide range of possibilities for manipulating wood yield. Because of the intimate relation between foliar growth and wood formation, the most promising starting point appears to be the increase in photosynthetic production by cultural and genetic improvement. This approach was successful in agronomic crops, and much research on increasing photosynthetic production and directing it into useable plant parts and products is currently underway. A similar approach to the manipulation of wood yield would be not only to increase photosynthetic production but to direct a greater proportion of this production into wood of high quality. However, in contrast to agronomic crops, forestry is not presently based on intensive cultural systems that can be readily adapted to utilize such highly productive methods.

Basic Considerations

BEFORE a meaningful program can be initiated to increase wood yield by optimizing photosynthetic production, several basic considerations must be recognized. In the past, the abundance of natural forests and the traditional concepts of forestry have dictated management decisions and cultural practices. However, for new forestry ventures these traditional concepts should be re-evaluated. New goals must be based on criteria that can be achieved by

using available and potential research procedures.

Among the basic decisions that must be resolved are:

Type of wood produced.—"Wood" means different things to different users, and wood yield is most generally defined in terms of some product objective. Although concepts of yield have been gradually changing, most are still bound to traditions in managing, harvesting, and utilization based on the size, form, and quality of individual trees. Our present dilemma in instituting new concepts of yield arises from a twofold desire—to preserve the great diversity provided by our natural forests, and to apply our current knowledge of scientific forestry. These desires are not necessarily complementary. Highly intensive forest management demands greater uniformity rather than diversity. One solution to this dilemma would be to redefine the concept of yield as the maximum dry-weight yield per unit land area. Our research effort could then be aimed toward maximizing photosynthetic production and distributing it into those tree parts and in a form that can be utilized most efficiently.

Length of rotation.—The length of rotation and intensity of silviculture practiced will be strongly governed by the kind of wood to be produced. Cogent arguments can be advanced to favor rotations of almost every length, but recent trends in forestry are toward progressively shorter rotations. For optimizing photosynthetic production, very short rotations would be essential to quickly and fully utilize the site as well as to capitalize on the rapid juvenile growth of selected species. Of far greater importance, however, basic research results can only be fed into a program that promises a rapid return of information. This flow of information between basic research and application is a necessary prerequisite to success. But it is notably absent in present-day forestry, and the possibilities become increasingly remote as rotation age increases.

Cultural practices and environment.—To realize the full potential of photosynthetic productivity, research programs must create new forest conditions rather than just imitate old ones. This means new attempts at manipulating the environment and the

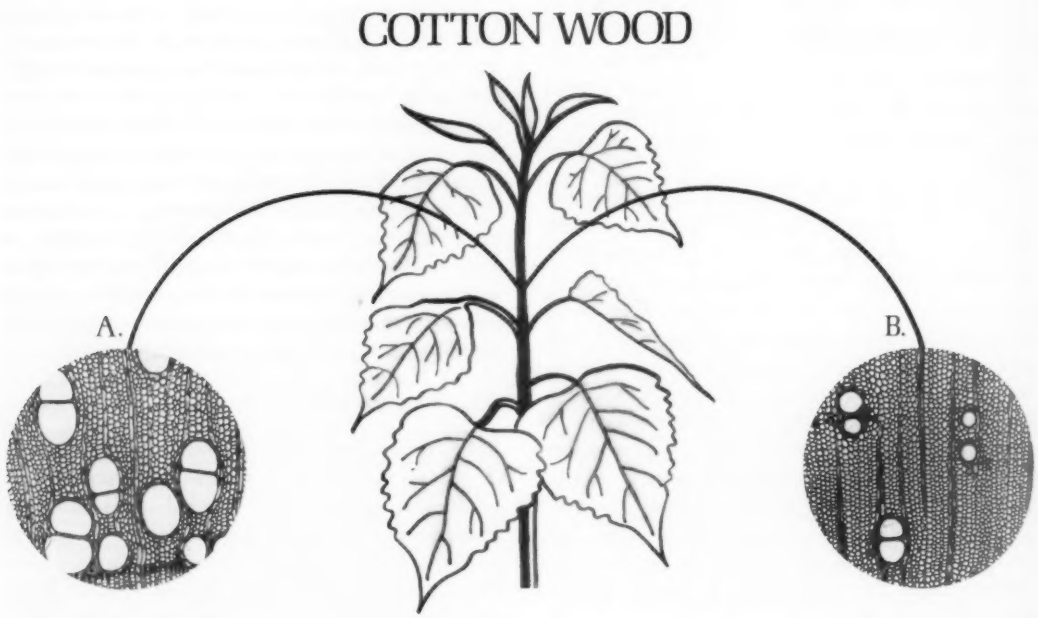


FIGURE 2.—*Cottonwood photomicrograph.* (*A*) Earlywood vessels in cottonwood are large and occupy a large volume of the wood during active leaf development. (*B*) As leaf development declines, a greater proportion of the photosynthate is diverted to thick-walled fiber production.

introduction of new cultural practices. Perhaps no area of forestry has been studied more intensively than the influences of environmental and cultural practice on yield. Although knowledge of these effects has been obtained almost exclusively by empirical method, a tremendous backlog of potentially useful information is nevertheless available for exploitation. These data urgently need re-evaluating so that meaningful yield comparisons can be drawn. From such comparisons, new practcies and modifications of existing practices can be readily introduced into the program.

Species.—The selection of species depends on what is to be done. Red pine and cottonwood have been cited as examples to illustrate the growth patterns for normally developing trees raised in controlled environments. However, since trees are highly adaptive organisms, different environments may bring forth radically altered growth patterns. These variations can be advantageously exploited for man's goal of efficient wood production. Species that exhibit a high level of genetic adaptability and diversity in response to the environment are likely to show large differences in yield potential. The species to be manipulated must therefore be carefully chosen on the basis of its potential growth traits.

Manipulation for Wood Yield

SUCCESSFUL manipulation of tree growth to increase wood yield must be performed with an awareness of the fact that man's goal may not necessarily be compatible with that of a tree growing in nature. Although nature's tree is a fairly efficient wood producer, its stem development and wood formation simply serve to place the photosynthetic and reproductive organs in a competitive position relative to those of other trees. Thus, tree growth must be manipulated in directions favoring those processes essential to man's goal of wood formation. The ultimate result of these manipulations may differ markedly from our present concept of an ideal tree. Growth manipulation can be accomplished in several ways.

Total photosynthetic production.—Trees are conservative organisms; thus, they assure their continued survival and reproductive capacity. Because of this conservatism, they do not fully utilize their natural environment. Research can provide numerous possibilities for improving the environment and for selecting genotypes that can utilize it more efficiently. These possibilities can be broadly classified into two groups: (*a*) more efficient use of the land area to optimize conversion of solar energy to chemical energy, and (*b*) more efficient use of the growing season. Under conventional forestry systems the growing site is not completely utilized by photosynthetic organs until quite late in the rotation. Complete utilization of the site should be attained at the earliest possible age. For example, initial selections might be for those trees that can produce maximum yields at relatively close spacings. Selections should also be made to achieve a balance among such factors of plant form as leaf display, internode length, and leaf retention.

Few temperate zone species utilize the growing season completely or efficiently. It should be possible to increase the effective growing season by a combined approach of culturally improving the environment and selecting responsive genotypes. Irrigation, fertilization, and tillage are known to prolong the growing season, and a balanced program could be attained by testing. A responsive genotype of deciduous species might be one in which the period of cambial activity extended well beyond that of height growth or the production of new leaves. Since mature leaves are the highest producers of photosynthate for wood formation, selections for good leaf retention combined with extended cambial activity might be advisable. For coniferous species, available evidence suggests that photosynthetic efficiency of the needles can be maintained at a relatively high level as long as consuming organs remain active. Therefore, increasing wood yield in selected species by extending the effective growing season appears very promising.

Distribution of photosynthetic production.—Maximum wood production does not necessarily follow maximum photosynthetic production. Neither does maximum photosynthetic production imply that the wood will be most efficiently distributed within the tree. Again, numerous possibilities for influencing the distribution of photosynthate may be suggested.

Crown size is highly correlated with wood yield. But large crowns and extensively spreading root systems can waste photosynthetic production under intensive cultural systems. By selecting for crown shape in terms of branch size and leaf arrange-

ment, or for more compact root development, for example, a more efficient wood producer may be achieved. The ideal tree would be one that produced the maximum quantity of useable wood from a minimum amount of foliage in a minimum area of growing space.

Selection for photosynthetic efficiency.—Individuals within a species are known to vary in photosynthetic efficiency. Variation may occur in the photosynthetic and respiratory processes themselves, or in the translocation and utilization of the photosynthetic products. Although these approaches may possess a valuable potential for increasing wood yield, translation of the necessary basic research results to practical applications would be considerably more complex than some of the preceding methods. Furthermore, the applied program would require constant re-evaluation as physiological research brought to light new areas for genetic improvement.

One of the greatest deterrents to the approach of manipulation for wood yield is the argument that knowledge obtained from young trees cannot be used to predict the growth of older trees. However, the transfer of knowledge between fundamental research on young trees and the more applied research on older trees can be maximized if the rotation age is shortened by intensive culture. Furthermore there is increasing evidence that the critical zone for regulatory control of wood formation occurs within the uppermost crown. It is this regulatory control combined with the total photosynthetic production that determines both the quantity and quality of the wood produced on the stem. Therefore, an understanding of these processes in young trees can be quite readily extrapolated to older trees.

Finally, it should be obvious that the manipulation of tree growth to improve wood yield requires a multidisciplinary approach. Thus the silviculturist, physiologist, geneticist, harvesting engineer, wood technologist, and others must all work together as a team in determining how to maximize production. It is only in this way, after the necessary administrative and management decisions have been made, that the basic research knowledge from many forestry disciplines can be applied to the single objective of increasing wood yield.

Portrait of The Underdog

FEW topics have drawn as much proliferation from authors as that of poverty, or, as some prefer to label it, socioeconomic deprivation. Social scientists who want to keep abreast of the latest developments would be faced with the rather formidable task of reading 652 books, periodicals, and pamphlets—all dealing with poverty and most of them written in the last 5 years.

They are all documented and properly annotated in a new publication by USDA's Economic Research Service, which is aptly and succinctly titled: *The Poor: A Selected Bibliography,* MP 1145.

A survey of the titles in the new bibliography reveals the wide range of approaches to poverty: "The Dusty Outskirts of Hope," "Who's Who Among the Poor," "Chicago's Hillbilly Ghetto," "Night Comes to the Cumberlands," and "Entrepreneurial Orientation of Farm, Working Class, and Middle Class Boys."

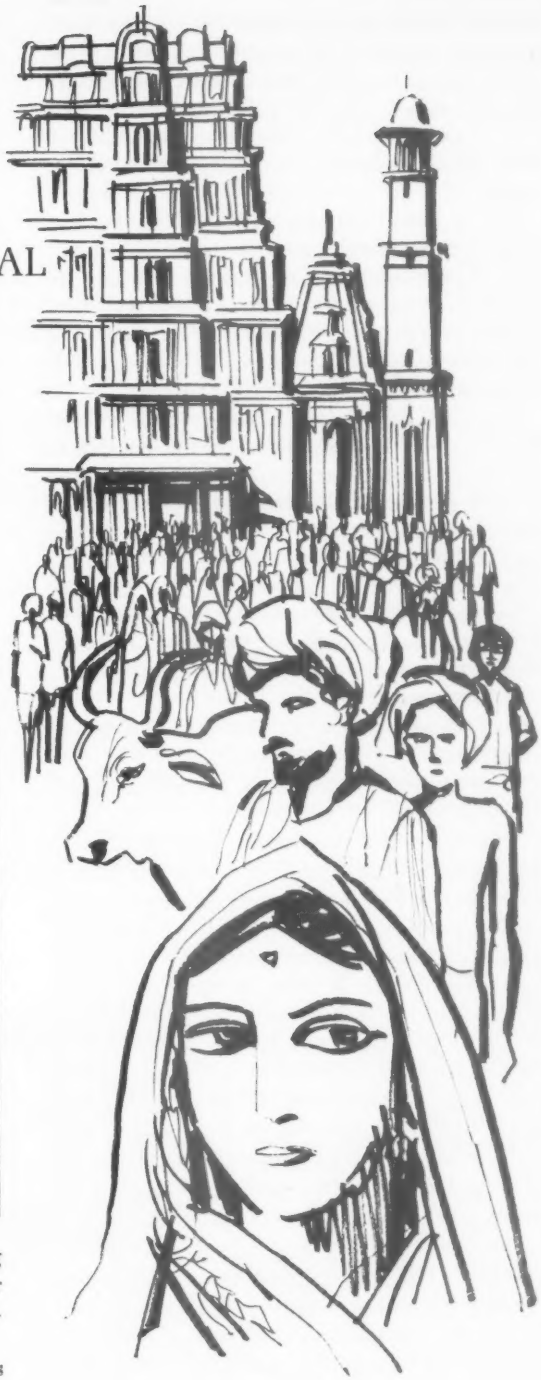
Compilers of the bibliography, P. R. Maida and J. L. McCoy, thoughtfully classified the entries in eight different categories, which are further classified in subcategories such as migrants, historical perspective, mental health, the elderly, etc.

Authors are listed alphabetically in a separate section. The two most quoted are S. M. Miller, Syracuse University and D. F. Riessman, Bard College, N.Y.—both with nine citations each.

As a service to readers, the Editorial Office of *Agricultural Science Review* will accept requests for single copies of the bibliography and forward them to the distribution office for mailing.

WHAT THE INTERNATIONAL BIOLOGICAL PROGRAM MEANS TO India

B. R. SESHACHAR



Early in November of last year, Dr. B. R. Seshachar, Chairman of the Indian National Committee for the International Biological Program, arrived in the United States for a 4-week tour of various U.S. IBP research projects.

During his brief stay in Washington, D.C., Dr. Seshachar very graciously consented to speak informally with science editors and reporters about the Indian IBP and the general status of science in his country. Agricultural Science Review *was represented at the meeting, which was arranged by The National Academy of Sciences. This interview-type article is based on a taped transcript supplied to* Review *by the Voice of America, and was further modified by Dr. Seshachar after his return to India.*

LET me first provide a starting point by giving you some introductory comments about our participation in the International Biological Program and its relevance to a country like India.

Like many other developing countries, India is faced with the problems of population explosion and

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inadequate food supplies. The vastness of our country, the great variety of our physical and biological environments, the differences in our ethnic groups, the great variety of social habits and traditions—some of which are many thousands of years old—all offer unique opportunities, perhaps unrivaled, for study.

In a country with such varied environments, a study of the major ecosystems is, therefore, important to obtain basic data on productivity levels, energy flow, and mineral and water cycling. It involves a close collaboration with a variety of disciplines. Thus, the study of environmental problems may be expected to receive extra impetus under IBP.

Because of this very significant worldwide biological program, it is now possible, for the first time in biology, to think in cooperative terms by scientists working in different countries—an advantage which will prevail long after the 5-year period of the program. Already we have several offers of collaboration from the United Kingdom, from the U.S.S.R., and from the United States of America. Such bilateral and multilateral research projects produce results more rapidly than if the participating countries did it alone.

I will be happy, now, to answer any questions you may have.

What support is the Indian government giving IBP?

The Indian IBP program has 56 projects, which are already being supported by our various government agencies—such as the Indian Council of Agricultural Research and the Indian Council of Medical Research or the Council of Scientific and Industrial Research. All of these are on-going projects, but there are a few new projects for which we have not yet obtained financial sanction. We hope that we can get some collaboration with U.S. agencies and that is one of the reasons I am here. Our situation is very much like yours in the United States, and this gives me a great deal of encouragement. Many of the IBP projects have worldwide interest; hence, collaboration is very necessary.

Another reason for my visit was to see how the IBP projects are progressing here in the United States. I have met some of the project leaders here—also visited a few laboratories—to discuss our mutual problems. I also attended a 2-day workshop in Estes Park, Colo., where we discussed the grassland project, and this was a very great revelation to me. In spite of what I have read in magazines, a great deal of new ecology is emerging, which is entirely unknown in other countries. I think your ecology program is one of the most vigorous I have seen anywhere in the world.

What does India expect to gain from the IBP program?

We have two very important problems—both linked very closely to each other—population and food. I put population first because man cannot live by bread alone. The problem of food still remains, despite the fact that we have had favorable monsoons, new methods of agricultural practices, and receptive attitudes by farmers. It is my hope that with the increasing production under IBP and our understanding of the adaptability of man—that some basic studies will start in our country and our food production will increase.

You understand, of course, that India has a great variety of habitats—the deserts, evergreen forests, tracts with the heaviest rainfall in the world, mountains, valleys, tropical and subtropical areas—we have every kind in India. Therefore, I am following with great interest your ecological and human adaptability programs because they fit in so nicely with the programs we can carry out.

What can IBP accomplish that other research programs cannot?

Several IBP projects are already included in our present agricultural programs, but there are other needs. A systematic survey of the environment with special reference to productivity at all levels will be of great benefit to us. As chairman of the national IBP committee, I have been looking around for a group of people to become interested in primary productivity.

What do you mean by primary productivity?

Photosynthesis is a good example. Although photosynthesis has been with us for a good many years, the analysis of this process is comparatively new. When new methods are available, you'll find that you can get more out of Nature and more can be produced.

Do you have any personal interest in any of the India IBP projects?

Yes. In my department we have a group of people who are doing some basic studies on fish biology, because fish is an important source of food. We have

another group working on reproduction of mammals. Much of this work is supported by the Ford Foundation.

Many hibernating animals in this country do not reproduce during winter. The ovum which has been fertilized remains in the uterus 3 or 4 months. It is a most extraordinary situation. It does not die, it does not develop, it stays. We are conducting some studies on this condition: What is happening? What is the rate of growth? Do the cells multiply? These studies, I believe, will have some relationship that we can apply to other animals.

I also have a man who is doing some sophisticated work on why insects choose the particular plant that they do—and a particular part of that plant. This scientist has developed some extremely fine physiological and physical methods by which he is able to say there *is* a substance in the seed which attracts the insect.

Where do you look for support for these university programs?

Scientific research in India is carried on under several auspices. We have 70 universities in the country. Not all of them are of the same standard, but quite a few are fairly good where research of high quality is being done. We have also a system of National Laboratories. This system administers about 35 laboratories of different disciplines. We also have a number of mission-oriented laboratories—leather, food, drugs, metal, roads—all kinds of things. These agencies try to answer the problems the country faces. Then there is the Indian Council of Agricultural Research where we have a number of projects outlined—more or less biased toward agriculture. The Indian Council of Medical Research is also sponsoring studies.

Only in the universities is there a lack of funds, because the functions of the universities—unlike the functions of other councils—are teaching and research. Many of these universities cannot do very sophisticated research because of either lack of competence or lack of funds. But in a number of active and vigorous universities, funds are not lacking. Any scientist at a university may submit a project proposal for IBP, and if it is worthy it will be supported.

Does the Indian government give any priority to IBP projects?

As yet, no. But I am trying to get the Ministry of Education, which deals with a great deal of scientific research, to consider the projects that are approved by the IBP to be good enough for them to support. My country, of course, is passing through the same kind of financial travails that other countries are. The nonscientists, unfortunately, are not always aware of the importance of IBP. For example, they cannot always understand basic research. But we do have now an authorization—a special fund—which the Planning Commission has set apart, and I expect to get something from them. We have got off to a rather slow start. But as you know, these are the trends in developing countries where scientific ap-

preciation is not spontaneous nor plentiful.

One of the underlying needs is to develop an awareness of IBP. Here in the United States it is developing very slowly. Do you see the same attitude in India?

I am afraid it is so in India. I don't know of any country where interest can be termed extremely vigorous. Much of the IBP work deals with factors of the environment—in other words ecology. And frankly there has not been enough attention paid to ecology. Molecular biology and genetics—these are prestigious things.

Recently I went to a very prestigious laboratory and not a single scientist had heard of IBP. They are not concerned with this. Our committee, however, is quite active in publicizing IBP to counteract this disinterest. For example, in one of its Sunday editions, *The Times of India* recently published a whole supplement about the significance of the International Biological Program to India. We had splendid coverage, and I am hopeful that this publicity—and our other efforts to educate and inform—will help to produce more favorable attitudes.

Since the program has now started, do you find that the attitudes of scientists are changing?

I wish I could say whole-heartedly "yes" to this. It takes much more than one committee or even a scientific community to do anything in this regard. IBP concerns not only biological and physical environment, but it also concerns man. Therefore we must have sociological thinking. Consider population, for example. Our Minister of Family Planning is very vigorously pursuing the idea of raising the marriageable age. To get this across to the millions of people in all parts of the country, where the weight of 2,000 years of tradition is sitting on the shoulders, is a very difficult problem. This means a lot of education. But we must begin.

What effect is your increased agricultural production of the last year or two going to have on the long-range problem? Will you be able to continue it?

There are two sets of factors; one is predictable, the other is not.

One of the predictable factors is the impressive advances we have made with new hybrids which we have imported from other countries and adapted for our use. Another predictable factor is the acceptance of these new ideas by farmers.

The unpredictable factors are the monsoons. We must depend on them, and the vagaries of the monsoons are well known.

But we are making significant advances—better than we have made ever before. It has been called an agricultural revolution. But I am a conservative. Some people say by 1971 we will be self-sufficient in the production of food. Perfectly good. But this is unpredictable. We did not pay enough attention to agriculture in the past. We thought of prestigious things such as atomic energy, steel plants, and big

dams. Had we paid the same attention to fertilizer production, I think we would have been much better off. These new strains of plants require a colossal amount of fertilizer and water.

During the past year our production has been around 100 million tons which is pretty good. This is by no means adequate, because we are adding the whole population of Australia to our own population every year. Any plans we make for food production must take into consideration this 12 to 15 million that we are adding. For this number of people you must plan for an additional 3 million tons of food every year. As I said in the beginning, food and population must go hand in hand. Any reform, any research, any attempt to meet with one must also consider the other.

Is there anything in your IBP program about population control?

Not as such, but we have some projects on human adaptability to high altitudes. We used to think that the Himalaya mountains were a natural barrier. But one fine morning about 5 years ago, the Chinese invaded us, and our soldiers were just not prepared for this. Subsequently we have done well, and our soldiers have learned to adapt themselves to these high altitude conditions—thanks to the Defense Science Organization.

Do you have any realistic viewpoint as to the eventual outcome of the food and population problem?

Frankly, no scientist can say exactly what is going to happen in any given year in the future. I was interested in an article in this morning's *New York Times*. It's a scenario-type article, and it starts like this: "It is 1994, and nobody can count the number of people that are slowly starving to death in the cities and villages of India. The whole population of the country is already over 1 billion." And so it continues . . . .

But we really don't know. I can tell you this, however, unless some drastic and impressive thing is done very soon in the field of population control, I believe much of this could come true.

In 1878 our population was 180 million. We produced 51 million tons of food; and, having provided for our people up to 28 ounces of food per day per person, we exported 4 million tons of food.

By the turn of the century, our population had grown to 256 million, and we already had fallen in the matter of providing adequate food for our people.

In 1951 our population was 360 million, and we did not produce any more than we did in 1878. That is about the time that we were desperately in need of food. The P.L. 480 Program began at that time and we imported 5 million tons of food that year.

In 1961 the population was 439 million. In 1967 we reached 500 million. Today it is estimated at 520 million. This means that we need *more* than 100 million tons of food. In other words, since our current food production is 100 million tons, we need to receive from the outside additional food to feed 20 million people.

The present most conservative estimate is that by 1977 we would have a population of 650 million and between 700 and 800 millions by 1980. If we have a very vigorous family planning program, we may be able to bring that figure down a little. But it is my belief that very drastic steps must be taken.

What rate of population growth are these predicted figures based on?

About 2.7 percent. It is now about 2.5. Our Minister of Family Planning thinks that we must bring it down to about 2. If we did, I can tell you that it would be a very spectacular development.

Does India have any guidelines or plans to head off this population explosion?

We have very few guidelines in regard to this. Japan did. Japan cut back the rate of growth in a single generation in a most spectacular way. We may not approve of her methods (legalized abortion) but she achieved control and today leads the world in this respect. At the most, what we can do in India is to liberalize abortion. To achieve an effective measure of population control, our program has to start in the villages. Here, resistance to the program is very strong . . . . I personally believe that sterilization is the answer to our problem.

It has been predicted that by 1980 there will be outright famine in India. Do you think that this is now being headed off?

By 1980 the population is expected to reach between 700 and 800 million. We should be able to produce at that time 150 to 160 million tons of food. Last year we were able to produce 100 million tons. It is quite possible that through advances in technology, newer varieties, greater acceptability of new

practices by farmers, and acceptance of newer foods—we may be able to stave it off. But this means a concerted effort by every single person.

Do you feel that India is capable of bringing about the revolution in food production which is needed to avert the predicted disaster?

I believe it can, provided that the tools are available—fertilizers and pesticides, for example. Our government is now directing all its efforts toward the production of these.

What about educational programs for the farmers?

One of the most spectacular things that has happened in the past 5 years is the starting of agricultural universities—the same as land-grant colleges in your country. We expect to have at least one agricultural university in every state—we already have five or six of them and they are doing some excellent work. But in addition to formal training, we must also have acceptance of new ideas by the farmer. I believe our Indian farmers will accept these new methods. Today, agriculture is a very flourishing industry. It is paying, and the farmers will certainly accept these practices. Our demonstration farms, of course, are also helping considerably.

Is there any feeling at all in India that IBP is fitting for the more advanced countries but has less real relationship to the current problems of emerging countries?

The appreciation of science itself in India is a new thing. The common man, of course, has no realization of IBP, but the scientist has, and he appreciates its importance. Since almost every project in IBP that relates to productivity has something to do with man, his existence, and his well being, I believe that nobody begrudges us the appreciation that is due to this program.

Thank you, Dr. Seshachar.

The Power of Attractants

THE world's most potent chemicals are not TNT, arsenic or hydrogen sulfide, as many people might suspect. Instead, the most powerful are probably the sex attractants found in some insects.

Insects must have some means of communication, especially at mating time, and scent is the most common communication. Some female insects produce a strong scent that attracts males from great distances at mating time. Some of the insects now being studied are the fall armyworm, gypsy moth, silkworm, honey bee, cockroach, boll weevil, and sawfly.

At the University of Wisconsin, H. C. Coppel and Fumio Matsumura are making a special study of the sex attractant in the sawfly—an important pest in Wisconsin forests which has defied most means of control.

They hope that knowledge of the sex attractant in the female may be by useful toward controlling or eradicating the insect. This would be done by using some of the scent to lure large numbers of male moths to a place where they could be destroyed. Or scientists might find a way to suppress the attractant in the female and thus prevent mating. Both methods depend on finding the attractant, isolating it, and learning how to use it.

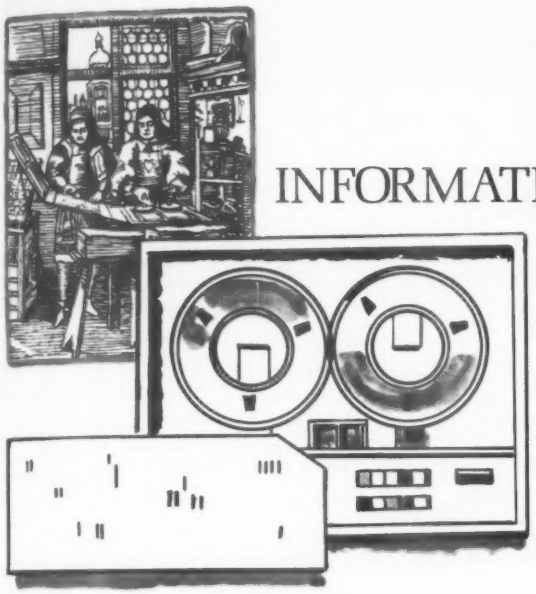
The virgin female sawfly produces her sex attractant in very minute quantities, but it is extremely potent. The average amount of the chemical found in one female sawfly (one 10,000th microgram) is enough to excite thousands of male sawflies if the material is distributed properly.

To obtain the potent chemical, air is blown over virgin females to pick up the scent and carry it through tubing where it is condensed out and concentrated in a solution.

They found that one female will produce 18 sawfly units or 40 picograms of attractant. (One picogram is one millionth of a microgram.) A few picograms of this attractant was enough to lure many sawfly males in the field.

The chemicals that attract other insects are called pheromones. For most insects, collecting pheromones can be a difficult and time-consuming procedure. For example, it takes 500,000 gypsy moths to collect 20 milligrams of sex attractant. Air must be passed over 10,000 cockroaches for 9 months to collect 12 milligrams of cockroach sex attractant.

From: *Science Report* No. 592
College of Agriculture
University of Wisconsin



INFORMATION SYSTEMS FOR AGRICULTURAL RESEARCH

WALTER L. FISHEL

ANYONE concerned with research, research management or administration, and the dissemination of research results requires some sort of information system—usually of a scale only to meet his personal needs. A file, library, or even a chronological stack of pertinent documents would qualify as an information system of sorts. In this article, the term "information system" refers to a more formal approach to the organization of information, which may be entirely manual, partly manual and partly computerized, or entirely computerized.

The term "information" probably has as many meanings as any word in the English language. To the statistician it means one thing; to the economic analyst it means something else. The term has still other meanings for the physical scientist, the librarian, or the layman. But from the standpoint of the information system "information" is considered to be any intelligible symbol. This can be a word, piece of data, diagram or figure, document, publication, or abstract. However, these constitute "information" only insofar as they relate to some logical framework or structure of knowledge. A number or word taken at random would not be considered information.

An "information system" may be defined as a logically organized body of procedures which processes input or stored data having specified characteristics. Its purpose is to supply information to someone who needs it—either as input into a study or research project, to solve a specified problem, or as the basis on which a decision is made. Figure 1 represents a schematic concept of an information system. Input information is processed and the same information or other information is emitted as output. Customers of the system influence its operation by setting up requirements as to the nature of the output. Feedback evaluates the acceptability of the system output and the system operation.

TYPES OF INFORMATION SYSTEMS

INFORMATION systems can be specified as to type in a number of ways. Probably the most pervasive classification is whether it is a *total* or *partial* information system. A total information system is one that satisfies all needs for information; a partial

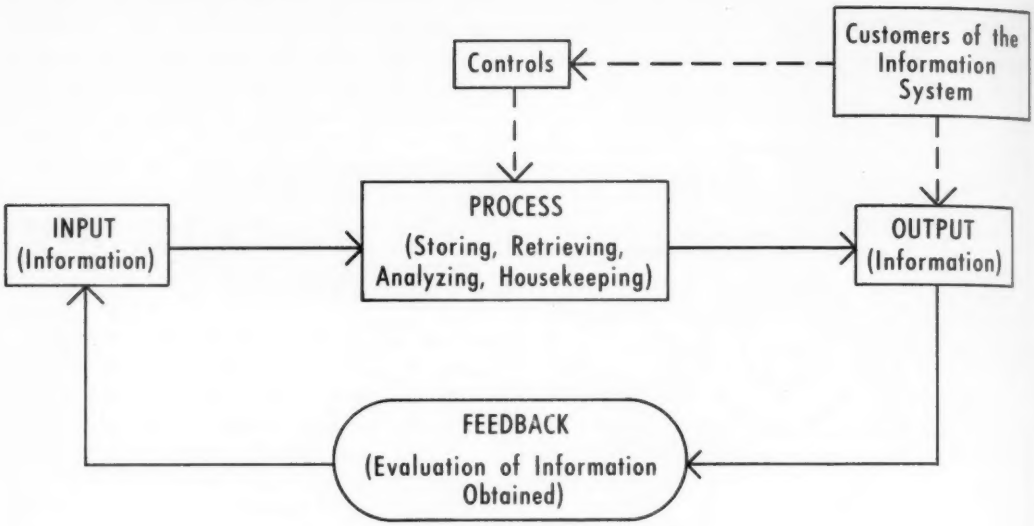


FIGURE 1.—A schematic concept of an information system.

system satisfies the information requirements of one or a few of all possible needs. As yet, total systems are extremely rare. The problems in establishing such systems are quite complex and difficult, and only the barest of guidelines have been established on how to implement them.

The usual information system is initially developed to satisfy only specific information requirements. As its functioning is debugged and its merit proved, additional systems may be developed or the original one may be expanded to satisfy additional information requirements.

Another distinction is between an *information system* and an *information retrieval system.*[1] *Information systems* are formalized processes for refining data to satisfy specific information needs. These would include inventory control, linear programming, PERT, accounting or budgeting programs, and a large number of other numerical analysis techniques. *Information retrieval systems,* on the other hand, provide a sort of reservoir for the collection and holding of data and information, which in turn may provide the data base for further refinement to satisfy the specific information requirements. This distinction applies to the characteristics of the process component of the information system (fig. 1).

The output of an *information system* provides more information than was put into the system process in the first place. This requires some procedures in the system process that analyze or otherwise manipulate the input information to provide relationships not apparent in the input information. In the *information retrieval system,* the information output is the same as the information input, possibly reordered, but still the same information. An *information system* frequently incorporates the functions of an *information retrieval system,* which is common for most business information systems.

A third differentiation is between *scientific* and *budgeting* information. Scientific information is the informational product of the research process; budgeting information is business data concerning the conduct of the research activity. Both scientific and budgeting information can, of course, exist in the same information system. They are not mutually exclusive. But structuring information systems to handle both types of information together has definite effects on the system's performance. The more tasks an information system is designed to perform,

[1] An unfortunate ambiguity arises in the meaning of "information systems" as a result of common usage. In this article, the italicized term, refers to a type of system as described in this section. The nonitalicized term refers to information systems generally, whatever their type of characteristics may be.

the less efficient and flexible it is for meeting specific information requirements. By structuring separate subsystems for scientific and budgeting information through a common channel, it is possible to include both types of information in the same physical system with only a slight loss in efficiency and flexibility.

A final subclassification of types of information systems relates to the *degree of detail* of the information included in the system; that is, whether the contents of the system consists of details or summaries of the actual information. This applies to both scientific and budgeting information. The principal distinctions among the four categories are as follows:

I. SCIENTIFIC-SUMMARY is abstracted information of documents used primarily to gain awareness of scientific activity in areas of interest

II. SCIENTIFIC-DETAIL is the recorded actual document or information generated by a research project or creative effort used where the specific information is desired, for example by research or extension workers.

III. BUDGET-SUMMARY is information aggregated by research programs, types of expenditures, organizational levels, or other similar conglomerates used primarily by administrators at the program level.

IV. BUDGET-DETAIL is specific information about a research or other operational activity used by research managers to determine results of specific courses of action on conducting a project or activity. For example, Area III would include information comparable to balance sheet statements, but Area IV would be more concerned with information comparable to cost accounting records and various measures of performance.

In summary, the dichotomy of types of information systems can be stated in a heirarchy of characteristics as follows:

Total—Partial
  Information system—Information retrieval system
    Scientific—Budgeting
      Summary—Detail

By far, the most common information systems to date have been Partial-Information Retrieval System-Scientific and Budgeting-Summary.

EXAMPLES OF INFORMATION SYSTEMS

WHEN one considers the variety of needs for information by the many people associated with agriculture, it is little wonder that there is such a profusion of systems in existence even in this one area. Nevertheless, there is a logical consistency in the characteristics of information systems that are available to agricultural administrators, researchers, extension workers, farmers, and others interested in some aspect of agriculture.

Many operations that collect and process information are neither computerized nor usually considered in the popular sense to be an information system, yet they satisfy all the necessary requirements. Probably the most notable of these is the *National Agricultural Library* (NAL), which is intended to satisfy the general needs of most people for information about all agricultural topics.

Another class of information systems more commonly associated with the popular concept is the various indexing or abstracting services. Sources of the information contained in these systems are published books, periodicals, journals, and research reports which are continuously monitored by trained staff or selected individuals in the profession. All of these systems are intended to satisfy information needs in relatively specialized areas for a much less generalized class of users. The information need satisfied in this case is that of being made aware of the existence of certain information. Two of the oldest and most established of such systems are the *Chem Abstracts* and *Thesis Abstracts.*

With the advent of computers, similar indexing services have been implemented for most scientific disciplines—many of these by commercial firms rather than public or semi-public agencies. Many new indexing systems are being established to supply very detailed information needs about a specific problem or topic. Two examples of such systems are *Selected Water Resources Abstracts,* operated by the Water Resources Scientific Information Center (Department of Commerce) and the *International Tree Disease Register,* operated by the USDA Forest Service.

Information storage and retrieval systems, or data banks, are similar to abstracting systems, but differ primarily in the types or sources of data they maintain. For example, the Smithsonian Institute's

Scientific Information Exchange (SIE) provides an indexed source of information about nonprivate research under progress throughout the nation, a service available to individuals in organizations that contribute reports of activities to SIE. Also, the Department of Agriculture's *Current Research Information System* (CRIS) for research activities and the *Extension Management Information System* (EMIS) for extension activities could be included in this class. The information base for all three systems is the project or activity statement.

The popular concept of data banks, as great reservoirs of numerical data available to users at the touch of a button, does some injustice to these kinds of information systems. Although some data banks contain almost entirely numerical data, these generally have some sort of analytical processor that manipulates as well as retrieves data in a manner desired by the user. The *Quick Query System* of the Economic Development Agency (Department of Commerce) and the *Minnesota Analysis and Planning System* (MAPS) being developed at the University of Minnesota are two examples of such data banks. Both contain data from the seven U.S. Government censuses as the primary data base, and both permit selective retrieval according to prespecified characteristics and output in a desirable format. In addition, MAPS will permit noncensus data to be incorporated in the data base in addition to any of the user's own data, and will provide a comprehensive array of analytical and graphical tools for processing the retrieved data.

All of the foregoing information systems have a substantial data base and a logical search routine for information contained in that data base. Any postprocessing of the retrieved information is certainly beneficial but is only of secondary importance.

In the class of information systems referred to as *management information systems*, the analytical procedure is the primary purpose, and any associated data base is mainly facilitative. Hence, the *management information system* may be concerned with refining information that is already on hand—either within or outside the system—or with more effectively collecting and tabulating data than can be done manually.

The previously mentioned CRIS and EMIS (and its State counterpart SEMIS) are primarily intended as *management information systems* relating to management or administration at an institutional level. Another of this type is the *Minnesota Agricultural Research Resource Allocation Information System* (MARRAIS), currently under development, which is an analytical program to assist research (and other program) administrators in evaluating the relative worth of proposed research (or program) projects. This system has no data base but accepts prescribed data input and emits numerical evaluation for the research projects under consideration.

A discussion of *management information systems* would not be complete without mentioning the array of systems available to individual farm operators. Most common of these are the large number of recordkeeping services now available through State universities, cooperatives, banks, and commercial consulting firms. One of these is Michigan State's TELEFARM mail-in service which provides, in addition to the usual tax-related account summaries, analyzed summaries of selected operations. Separate from these general farm management information services are various enterprises such as the well-known *Dairy Herd Improvement Association* (DHIA) records, optimum feed mix programs, and soil fertility evaluation and recommendations. Also in the early stages of development is still another type based on simulation of specific events (such as machinery acquisition), enterprises, or entire farm operations by which the results of decisions on farm operations can be evaluated before the final decision is actually made.

Because of the widespread interest in creating new information systems, considerable effort has been devoted to the development of *information system languages*. These are computer-based subject-independent programs which individuals or organizations can use to organize data from their own field of interest for effective storage and retrieval operations. The array of available languages is considerable, each with its own particular advantages in specific applications. Among these are the *Generalized Information System* (GIS), *Information Oriented Language* (INFOL), *Basic Index and Retrieval System* (BIRS), *Quick Query System* (QQS), and a commercial version of QQS.

A different type of information system language includes those programs designed to facilitate users' self-maintenance of what is occurring in their areas of interest. This service may be especially useful where user interest overlaps the information

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 FOR AUTOMATED DOCUMENT RETRIEVAL SYSTEMS.=A FORMAL INDEXIN     WALTTS-63-FIL
ECTIVENESS FOR DOCUMENT RETRIEVAL SYSTEMS.=A MEASURE OF EFF     DARMQA-62-MED
PPLICATION TO AUTOMATIC RETRIEVAL SYSTEMS.=A NEW EFFICIENT      SALTG-63-NES

DARMQA-62-MED  DARMSTADT QA
                  A MEASURE OF EFFECTIVENESS FOR DOCUMENT RETRIEVAL SYSTEMS.=
                  INTERNATIONAL ELECTRIC CORP., PARAMUS, NJ, IEC TECHNICAL
                  NOTE, FILE NO. P-AA-TN-(0043)-N, DECEMBER 18, 1962
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FIGURE 2.—The bibliographical reference at the end of the first 3-line group refers to author, year, and initial letters of the first three key words in the title. The bibliography listing under DARMQA–62–MED gives the complete title, source, etc.

coverage of several information sources. In any case, the primary purpose is to speed up the process of getting the user and the specific information he wants together more rapidly and with a minimum of superfluous data.

The Key-Word-In-Context (KWIC) is one such system which presents an alphabetical listing of keywords in titles, abstracts, etc. The immediately preceding and succeeding words are "wrapped around" the keyword, and the entry is indexed to a bibliography (fig. 2).

A more specific information system language of the same type as KWIC is the *Selective Dissemination of Information* system which relates stored keywords describing each user's areas of interest and compares these against keywords of new materials. A number of variations of these two types are available.

Although there are many types of structures for handling and processing data, the preceding discussion essentially covers the principal types of information systems that one might encounter.

GUIDELINES FOR ESTABLISHING A SYSTEM

SINCE the primary purpose of any information system is to facilitate or make more efficient the performance of individual operations—whatever these may be—it is necessary first to evaluate the various functions relating to agricultural research and the kinds of information needed to perform these functions. Associated with each of these functions are needs for certain types of information, and each function is responsible for generating certain types of information (table 1). In this discussion, extension function should be interpreted as that of reporting research results. Futhermore, the research process is the central interest in this discussion and not information dissemination.

The functions listed will be carried out in any independent research organization—Federal, State, or private. In addition, there are both formal and informal information links among various combinations of these organizations at one time or another, just as there is a flow of information among functional groups within each organization.

Identifying Benefits and Costs

IN determining the need for a formal information system, it is necessary first to: (*a*) identify the areas of information accumulation and use that are likely to be needed for an information system, and (*b*) determine the economical justification of an information system in a given area. Several general criteria can be suggested as a means of identifying areas of accumulation and use:

Areas having definite needs for information are not currently being satisfied. This criterion is so obvious that it is probably overlooked quite often as an excellent initial indicator of an area. Conversely, efforts to establish formal information systems may frequently extend into areas in which there is no particularly strong need for information.

Information is desired or obtained from relatively complex areas or from areas in which the means or methods for getting the information are complex. This criterion should not be confused with volume of information or data. Although a certain amount of data is required to justify any formal information system, volume as a factor generally will influence only the decision as to whether the information system will be manual or computerized.

Collection or analysis of information in a particular area requires repetitive or costly methodology. Such areas may be characterized by being somewhat disjointed, separate parts being performed by different individuals or groups, and

TABLE 1.—*Agricultural research organizational functions, information needs, and information outputs*

Information required	Function	Information generated
Available resources for conducting research	Administration	Research programs.
Areas in need of research		Current expenditures.
Resource requirements for conducting research		New budgets.
Progress of research programs		Business reports.
Available resources	Management	Research programs.
Specific research needs		Current expenditures.
Operational requirements		New budgets.
Progress of research projects		Business reports.
Stock of facilities and services available	Facilitative	Stock of facilities and services available.
Facilities and service needs		Facilities and services supplied.
Previous research conducted	Research	New knowledge.
Available expertise		Research projects.
Specific data		Project progress reports.
Research results	Extension	Information reports.
Existing similar reports		
Substantive information		

repeated periodically—such as various business reports.

There is a definite need for "recurring" information. Table 2 shows where these needs might occur. In the table, the "same information" can be interpreted as being actually identical or it can be different information with identical structural characteristics. A similar definition would hold for the "same source."

Information to be included in the system must be documented or capable of being documented. Final determination of the desirability of an information system is based on a comparison of the value it contributes and the cost of establishing and operating it. Unfortunately, there is no clearly defined way to estimate either total value or total cost; not all criteria are quantifiable. Hence, subjective evaluation must be used to justify a system. Following are some of these criteria:

Savings in time and cost of procurement.—Where applicable, the straightforward savings in time and cost in obtaining given information through an information system should be compared with alternative means.

Value of new information.—Consider the value of obtaining certain scientific or budgeting information that would not otherwise be available or available only at prohibitive costs.

Manpower savings.—The energy and efforts of certain staff people may be best utilized in decision-making activities rather than information development.

Quality of decisions.—An information system may improve the quality of decisions in research management and administration and result in more knowledgeable research project development and conduct by researchers.

Elimination of duplication.—A system may reduce the total cost of research by eliminating duplication of efforts.

Some of the factors to consider in estimating the cost of the system are as follows:

Initial cost of setting up the system.—This would include the study to determine the need and characteristics of the system and the initial facility and equipment costs. Another initial cost, if applicable, is any temporary loss in performance of clerks or even management personnel resulting from confusion during changeover from current record-keeping procedures.

Operating cost of maintaining the system.—This includes materials as well as equipment rental and salaries of specially qualified personnel.

Personnel efficiency.—A newly established system may, for a time, cause a drop in the efficiency of personnel performance because of (*a*) inability of

existing personnel to adequately cope with new information collection requirements, or (*b*) inability of management to adequately understand and work with the information generated.

Actually, estimates of use-rates for system objectives provide a precarious basis on which to calculate the quantifiable aspects of the evaluation. Because of the fixed or semifixed costs for setting up and operating a system—such as payroll costs for clerks or information supervisors—it is fairly well established that a system cannot be justified for a single information need. To build up an adequate use-rate to justify the cost, it may be desirable to develop a system to serve the information needs of more than one function or more than one organization.

The multiple organization approach can be horizontal (with like organizations) or vertical (with unlike organizations), but obviously ones using the same information. However, in either case, one must expect certain limitations or restrictions on the scope and performance of the information system.

Choosing the Right System

IN the early planning stage, it is extremely important to consider the distinction between the two types of systems—*information system* and *information retrieval system*. The *information system* delivers more refined information than that from the *information retrieval system*, because more is done to the input information in order to satisfy the user requirements. Although both systems are need-oriented, the difference in the approach to devloping a system is that the starting point for the *information system* is very specific information requirements, but for the *information retrieval system* more general information needs must be considered. Greater emphasis must be given to possible uses rather than specific uses of the system in the case of the *information retrieval system*. For that reason, it is more difficult to develop. Because the *information system* is much less flexible than the *information retrieval system*, it may be necessary to consider further refinement of data or the setting up of subsystems outside any retrieval mechanism.

Areas To Be Serviced

ALTHOUGH there are certainly significant advantages to having an information system that includes several organizations, or at least more than one, there are at the same time equally significant limitations, restrictions, and just plain problems involved. In addition to the advantage of increased efficiency of operation through greater volume handled, there is probably an even greater advantage in having ready access to information that would otherwise not be available or available at some expense. For example, for a number of uses, the output of CRIS would be of significantly greater value to State researchers and administrators than that of their own system, which might contain information only for that State.

Caution should be used in combining essentially unlike organizations in a single information system.

TABLE 2.—*Recurring information situations in an input-process-output context*

System component	Recurring situation	Example
Input	Same information from different sources	Yield data from different plots.
	Same sources but different information	Scientific and budgeting information from a given project.
Process	Repeatedly the same process or various ones of a set of processes applied to collected data.	Retrieving and filing project information for different uses or users.
Output	Same format from different information	Periodic budget reports by individual departments or projects.
	Different format from the same information	Preparing different project reports from the same project information.

The important criterion is operational efficiency—whether one physical system could handle all the information at a lower unit cost than several parallel systems. Each area will likely have its own terminology. Even the logical systems for storing and handling information might be different. Hence, even in a single physical information center, there would practically, if not literally, be as many separate information systems as there are unlike organizations.

Although separate physical systems for each unlike organization or type of organizations might be desirable, built in compatibility in the various systems can easily be justified. Areas of information in each type of organization may be of common interest to other types of organizations. To permit effective cross-over among information systems by users, these areas should have compatible features. For example, key words in these areas should be uniformly defined for all information systems using this same information. Or, some sort of interpretive routine should be introduced where such common definition is not practical.

Even within a single profession, words or phrases are sometimes interpreted differently. The same can be true within a single organization, but such differences are more easily clarified than if they occur among different organizations. Likewise, if summarized data is to be included in a multi-organization system, the problem of interpretation and definition may be particularly acute. Summarization of budgeting information is a good example of this.

There are certain limitations on what can be included in multiorganization systems, simply from the standpoint of volume of information to be processed. In general, there is a definite inverse relationship between size of the information system and the scope of the information to be included in it.

Although individual organizations might need the same type of information, specific needs would be different, and each would not be interested in the others. This distinction would apply to both budgeting and research. Certain information is going to be maintained by each organization anyway; therefore, the marginal cost of maintaining the whole system might not be that much greater. Again, the comparison between CRIS and a State system points out this distinction.

One problem area that needs to be given a great deal of thought is that of physical access to the system—that is, the physical location of the system relative to the location of actual users. To be very practical the information system must be readily available to its users. If there is a significant physical separation, a special communications systems may need to be installed, which naturally adds to the cost.

Finally, there is always the problem of the willingness of individual organizations to cooperate initially in a multi-agency system and to thereafter submit information to the system in a common form.

System Construction

IN setting up an information system, one of the cardinal rules is that the new system should be as simple as the one it replaces—preferably simpler. Data collecting should not be more complex than without the system. Rules of operation should be clear and understandable to both contributors and users. An information system is not an end in itself; its primary purpose is to facilitate. Thus, any efficiency gained by one group should not be offset by a loss of efficiency by another group.

Where there is the possibility that the information system might cause a hardship, careful attention should be given to determining ways of adjusting system procedures as necessary. In some cases this might require restructuring part of the overall system, such as building a subsystem to handle a particular area. For example, information requested in one form may be contrary to the form in which the contributor actually uses it. If the contrary form causes a hardship, the system and not the contributor should be the prime suspect for being changed.

Both inputs and outputs of the system should not be over-refined. Moreover, the user of the information generated by the system must know what the output means. All of these factors underscore the point that the information is not the end objective. In all cases, it is only a component of a much greater system concerned with generating new information.

In developing the actual mechanics of an information system, the possible future uses must be carefully considered along with the known current uses for which the system is intended. However, even known current uses require careful planning. It is certainly easy enough to develop a system where both the specific uses and form of the output are

known. On the other hand, if the exact form or forms of the output are not explicit, then the uses can only be bounded. In such cases, the bounds on the possible use of the information system must be clearly defined. Such a system would not be particularly difficult to develop, but construction of the feasible alternative outputs does require careful prior planning.

Once a system is established, the problem of fitting in unanticipated uses is often handled by fragmenting the information system with a subsystem to handle each class of information needs. Although this is the simplest way out of such a dilemma, it very likely would not lead to a very efficient operation. A much better plan is to build the required flexibility into the system operations in the first place. This is particularly applicable where (*a*) the system is initially set up to satisfy one or two urgent requirements for information, and (*b*) the agency has a fairly good idea that the scope of the system will be expanded later.

A final area that needs to be weighed carefully is that of the physical characteristics of the information system, primarily to what extent the system will be manual and to what extent computerized or otherwise mechanized. As indicated earlier, a formal information system need not necessarily be computerized. Many good information systems are basically manual. Volume probably is the key factor that determines the choice. Either a lot of information handled a few times or a fair amount handled many times generally means that a computer is needed. This point, however, depends on the characteristics of the particular information system developed and the economies of the situation. The worst thing that can happen to an information system is for it to be developed around an existing computer program. Moreover, the variety and characteristics of equipment and mechanics are constantly changing and expanding.

PROBLEMS IN STRATEGIC PLANNING

In the development of an information system, two general planning phases are recognized: the "strategic" planning phase and the "operational" planning phase. Strategic planning encompasses (*a*) delineation of the general structural characteristics of an information system, based on an evaluation of information needs, (*b*) alternative information sources, and (*c*) pertinent related environmental factors. Operational planning refers to the detailed design of an information system once its general structural characteristics have been specified. Obviously, the two phases are interrelated. A discussion of the operational phase is outside the realm of this paper, since that phase would be more the concern of information specialists.

An information system, as a facilitative device, derives its justification for existence in the extent to which it helps individuals make decisions—whether they are research-related decisions or business-related ones. Information however is basically a highly personal thing. It is useful only as it fits into each individual's own decision-making frame of reference, and no two frames of references are entirely alike.

The process of establishing an information system, therefore, is essentially an attempt to identify enough common points in these frames of references to make it more efficient to supply the information through a common system instead of letting individuals search for needed information separately. The specification for an information system then becomes a matter of trade-offs between (*a*) specific personal information requirements or preferences and (*b*) the scope of benefits provided by the proposed information system. A system may provide a single individual's total information needs, or, on the other hand, a relatively few needs for a very large number of individuals. The trick in strategic planning, obviously, is to determine the proper balance between these two extremes.

Good strategic planning can help to avoid the problem of overlapping of information in systems operated by both commercial and non-commercial organizations. In some cases, such as for CRIS and SIE, there is some direct duplication of effort. In other cases there is more of an indirect duplication. The principal difficulty arises when different systems have different orientations for the information problem. For example, some systems are designed to make persons aware of certain information in a number of subject areas; others are designed to include the content of a single subject matter or discipline while encompassing several functions. Such duplication of effort is hardly an economical way to supply information. Likewise, if information needs for a group of researchers with similar infor-

mation requirements must be satisfied by addressing a number of separate systems, the results may be every bit as inefficient and costly.

A system will very likely best satisfy the information needs of the user group for which it was initially developed. But any change in the status or functioning of the original group may introduce new management problems. Examples of such changes would be (*a*) expansion in the size of the user group with perpetually increasing fringe interest, and (*b*) an increase in the incidence of such fragmented groups together with increasingly overlapping information content.

These concerns in strategic planning suggest the desirability of considering the whole problem of information needs and supplies in the framework of a total information system. This does not mean that a single unit system should be developed to serve all needs. Instead, a single structure should be devised that could encompass the whole spectrum of related information systems as well as guide the synthesis of new ones that might be proposed. Within such a total information framework, the efficient allocation of information with varying degrees of specificity among different levels of organizations (such as between State stations and USDA) or among types of organizations (such as between universities and commercial organizations) would appear to be feasible without harmful omissions or costly overlapping.

Such an approach to information system planning would be very much like metropolitan planners enjoying the luxury of starting from scratch in developing services for all residents rather than trying to compromise the various city and suburban needs with a heterogeneous aggregate of service resources. Since the development of information systems for agricultural research is still in its infancy, the concept of the total information framework appears to be the most logical approach.

How Long Is A Foot?

IF a yard is the length of an arm, whose arm should be used as the standard?

Despite the fact that Jefferson, Adams, Franklin, and Lincoln all advocated the metric system of measurement, the United States has not yet officially adopted it—even though it is legal here and more than 90 percent of the world has adopted it.

In 1960 virtually the only countries not officially on the metric system were the English-speaking nations. Since then, the British Government has ordered a changeover to be completed before 1975. A Canadian commission expects to report favorably this year.

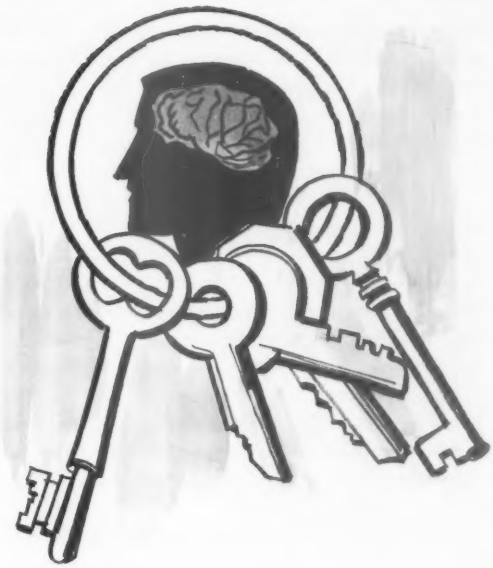
A 1967 study estimated that a 20-year conversion period would cost about $11 billion. But it has also been estimated that *not* changing costs the United States $10 to $25 billion annually in world trade. Each year's delay boosts conversion costs by about 7 percent.

As a result of congressional action in 1968, a 3-year feasibility study is finally underway in the United States. Many major manufacturers, the military services, all the sciences, international sports—among others—have already moved into metric designations.

Recognizing the apparent inevitability of U.S. adoption of the metric system, the University of Vermont Extension Service is making a special educational effort this year to bring an understanding of the problems to Vermonters.

From: "How Long Is A Foot?" by Fath K. Prior
Vermont Farm and Home Science
11:3, 1969.
University of Vermont

THE SOCIAL CONTROL OF SCIENCE



LEE A. DuBRIDGE

THE subject of the social control of science is, of course, a broad one and a difficult one to discuss. Not the least of our problems is that it is hard to find two people who agree on what is meant by social control, and in addition, people do not always agree on what is meant by science.

Possibly the second question is the easier to deal with. I shall arbitrarily assume, for the purposes of this discussion, that when we speak of science, we are talking about *natural* science—that is, the study of nature. Thus, I shall not discuss the social sciences but only the physical and life sciences. And, because of my own personal background of knowledge, I shall probably talk more about the physical sciences and their applications—and somewhat less adequately about the biomedical sciences and their applications.

But at once we face the critical question: As we speak of science, are we referring to the basic sciences themselves—the pure search for knowledge? Or are we talking about the applications of the knowledge we have already gained to the solution of practical problems of whatever kind we may think of—industrial products, military defense, the cure of disease, the growing of more food, the improvement of the comforts of living, or the alleviation of many social ills?

Let me say at once that when I speak of science today, when I use no qualifying adjectives or phrases, I shall refer to *basic* science. But, in common with others, I shall use the term *science* in both the active and the passive sense. In the passive sense, basic science means the body of knowledge about nature which has been accumulated over the many centuries during which men have sought to probe the secrets of nature. In the active sense, science means the search for new knowledge about nature—new knowledge about the atoms and the stars, about matter and energy, about simple and complex molecules, about living cells and the process of heredity and the mechanism of the brain.

When we speak of science in the passive sense, I assume we must all agree that there is not much we can do about it. The knowledge is there; it exists. Nothing we can do will diminish the storehouse of knowledge which we have accumulated. All we can do is ask how that storehouse may be enlarged by pursuing science in the active sense; or how that knowledge is to be put to use—the subject of applied science.

My first thesis is that we do not have, and we do

This article was adapted from an address given by Dr. DuBridge at the "Conference on the Social Controls of Science and Its Applications" at the University of Chicago, Chicago, Ill., Mar. 20, 1969.

not want, any organized social controls over the active pursuit of basic science—the pursuit of new knowledge—other than the inherent controls which exist in the minds and hearts of the scientific investigators themselves. Scientists must be free to pursue the truth wherever they can hope to find it.

There may, of course, be inadvertent controls over the areas in which a scientist pursues his investigations, stemming from the fact that some investigations are more expensive than others. Also the total supply of resources which any nation can make available for scientific purposes is limited.

All of this is inherent in the nature of things in any society, whether it be democratic or autocratic. These are the inadvertent controls over the pursuit of knowledge which, however unfortunate or fortunate they may seem in individual cases, are not going to go away.

The point is that no Federal, State or local agency, public or private, nor any combination of such agencies in the United States, is now trying to suppress or prevent the valid pursuit of scientific knowledge in any field. Quite the contrary, many public and private agencies are actively seeking out scientists with good ideas whom they can support within the limits of the funds available to them. And taking all these agencies together, there is support available for essentially any field of basic science. So I will repeat my thesis: We do not want and we do not have any social controls over the pursuit of basic knowledge. We do not desire social controls over how a man thinks or what he seeks to learn.

If we agree that there *can* be no social control over the knowledge which already exists, and we do not *want* social controls over the pursuit of new knowledge, then what do we mean by the social control of science? The answer, of course, is obvious: What we are really talking about is the social control over the use of scientific knowledge. We are talking about the social control, not of the pursuit of pure science, but of applied science.

What do we mean by social control? Do we mean the control of applied science by the government—Federal, State or local? Do we mean control by society at large, through the powerful force of a pervasive public opinion? Do we mean control by the scientists themselves by choosing, in accord with their own consciences or interests, the field of applied science in which they choose to work? Do we mean that the scientists who uncover new knowledge about the physical world shall somehow be organized in such a way as to dictate how that knowledge shall be used? (If we mean this, how do we bring in people like Newton, Galileo, Lavoisier, Darwin, Maxwell, Bohr, Einstein and all the rest who are no longer with us?) In short, what kind of social controls over applied science do we want, what kind do we have, and what is the purpose of social control?

Whether we like it or not, social controls over applied science do exist and will always exist. The nature and direction of these controls will vary from one nation to another, even from 1 year to the next, and from one subject to another. But they are there—in a variety of forms and with a variety of objectives. The question is: Are they—in the United States, let us say—the right forms and do they aim at the right objectives?

Before we can answer this we must examine just what these controls now are, how they operate, where they succeed, and where they fail.

Control by Individuals

FIRST, of course, there is the control exerted by the individual—acting either alone or in concert with his colleagues, through formal or informal organizations or associations, large or small. When individuals in some numbers, independently or together, decide they will or will not work in a certain field of applied science, this will result in a certain degree of control over progress in the field.

This action can, of course, if it is widespread, be a very important source of control. In recent years, for example, large numbers of able college students have elected *not* to seek degrees in engineering. Thus, enrollments in this area have leveled off or even declined. Applied science as a whole is therefore not progressing as rapidly as it would have if there had been an increase in engineering degrees. Some areas, such as civil engineering, have been affected more than others, such as electronics.

No scientist or engineer can possibly be forced to work or study in any field of pure or applied science (or in science at all) if he does not so choose. No scientist or engineer can be forced to accept a job in the laboratory of any company or agency which is engaged in any kind of work of which he disapproves or for which he has no taste. By the same token, no one has the right, of course, to pre-

vent any other individual from accepting or continuing a position in any legally constituted laboratory of his choice.

The success of a company, a government agency, or an educational institution in recruiting talented people for any area of applied science in which it is interested will, of course, determine the rate of progress of its work—may even determine whether such work can be pursued or not. Here, then, is a social control of very potent possibilities, depending in a perfectly democratic way on the voluntary choices or the persuasive efforts of many individuals.

People being what they are, we cannot of course expect that such voluntary action by individuals or groups will very often bring to a complete halt any specific area of applied science. Other individuals or groups may think this endeavor very worthwhile or important or attractive and will enter into it with enthusiasm and effectiveness.

When an individual argues, therefore, for additional social controls over applied science, he is not advocating something which will force him to do what he does not choose to do; for no agency in this country can do that. But he is seeking to interfere with the free choice of others.

Control by Universities

THE second agency of control is the universities which can fund, or fail to fund, depending on their resources and objectives, specific applied science projects. Many institutions are now funding research and development in urban affairs, food, population, health, the technology of developing countries, aeronautics, communications, space technology—and so on through hundreds of specific areas. Each such institution is seeking to apply our knowledge of science to areas which it deems appropriate, desirable or important to the general welfare. Collectively, such institutions have great influence on the directions which applied science is taking or may take. If universities as a group do not pursue applied research in a particular field, the progress in that field will be hampered.

Lack of talent or of funds may impede progress in some areas, and emphasis may then turn to other areas where such shortages are less serious. But funding levels available may depend on conditions outside the control of a particular institution. A private university may find donors willing to fund

some areas but find no one whose generosity encompasses other areas. State universities must depend on actions by legislatures. Both will depend on Federal funds in certain fields, but will again fail to secure them in others. Universities plus their funding sources do, however, constitute a control and set a direction for applied research.

Control in the Marketplace

COMMERCIAL companies carry on a large segment of our applied science activities. Leaving aside for the moment that portion which is supported through Federal sources, companies have powerful incentives to pursue engineering and development work in areas which will improve their productive efficiency or result in new or improved products for consumers. Out of industrial research there has emerged in the 20th century, and especially in the last 20 years, an amazing array of products which have enormous appeal, desirability, and usefulness to millions of people in this country and throughout the world.

Here we find the great example of social control in a democratic society—control in the marketplace. No one is forced to purchase a product which he does not like or which he thinks is harmful to himself, his family, or his community. And many an industrial company has found that a huge invest-

ment in research and development on some consumer product has come to naught because consumers in large numbers do not buy the product.

The control by the marketplace can be a very powerful one, and is one that can be altered markedly through the action of individuals and voluntary or government organizations. Consumer organizations can encourage people to buy one product and discourage the purchase of others. Massive advertising campaigns can have pervasive market influences, positive or negative. We are witnessing right now a two-sided campaign for and against the smoking of cigarettes. The market effect of this is still uncertain, but in the end it may be very great indeed.

However, there are those who believe that though the control of the marketplace is great and, for the most part, constructive, it is not enough. People insist on buying things that are not good for them, or buying things that are useless or things that may harm others. But the marketplace is there, and it is very powerful. Our task is to find ways to use it and guide it into even more constructive channels. Public information campaigns, government regulations to enforce truth in advertising, consumer organizations which test products and disseminate their findings—all these and other mechanisms in which we as individuals can participate and which we can encourage may greatly influence the use of scientific knowledge in the field of consumer products.

Control by Government

WE turn now to a major mechanism of social control of science which most of us think of first when we discuss this subject—namely the government—Federal, State, or local.

Governmental agencies may exert control over applied science in several ways: (1) By the regulations which they adopt and enforce on the advertising and the use of products or the pursuit of projects which are judged to be harmful or dangerous or which have adverse environmental or other effects; (2) by the way in which funds are allocated for the pursuit of research and development aimed at specific end-products; and (3) by the things which government agencies build or buy, or seek to buy, be they military weapons, airplanes, highways, dams, power stations or any of the hundreds of products or facilities which government agencies believe are needed to promote the public welfare or to satisfy a public requirement—some of which, of course, are not happily received by some segments of the public.

It would, of course, take a very large book to describe and evaluate all of these actions of government which influence the way in which scientific knowledge is put to use. *In toto,* they constitute an enormously powerful and pervasive social control over applied science. And this control can, in the long run, be expanded, contracted or altered in whatever ways the public, through its elected representatives, may demand.

Effective Use of Controls

THE problem, therefore, is not so much how to invent social controls as it is how to use more effectively and constructively the ones that we already have. The mechanism for social control is already present. The question is: What do we want these controls to achieve that they are not now achieving?

It is not difficult to set forth in a general way the goals we all seek to achieve in the use of scientific knowledge. In the negative sense, we all wish to prevent or discourage applications of science which are harmful to individuals or to groups of individuals, or which despoil our environment, or which unnecessarily waste our precious natural resources, or impede our progress toward social welfare and justice and toward world peace.

On the positive side we wish to encourage and support those applications of science which enhance the welfare of people, which make our country and the world a better place in which to live, which will improve the quality of life in our cities and in rural areas, which will reduce the dangers of wars between nations.

All this is easy to say—and very hard to accomplish. For example, we all wish to reduce air pollution. One way to do this (in part) would be to prohibit the use of any vehicle which burns gasoline—or to prohibit the sale of gasoline itself. (That would cure the smog problem in Los Angeles, for example.) We might also prohibit the operation of any industrial facility which discharges contaminating products into the atmosphere. But such sledgehammer methods are clearly undesirable and

unworkable. A better way is to encourage research aimed at the development of better technology for reducing such pollution. And then when better technology is available, we should encourage or require its utilization. This is indeed being done, although the pace of advance may seem slow. We are now seeking new mechanisms to improve and expand our activities in this direction—and surely, we need better regulation and management, using existing technologies.

This is but one example—and there are hosts of others—in which a primary role of government should be a positive one and not solely a negative one—where government should not retard but advance the progress in applied science in a variety of ways which will contribute to social progress. Science, throughout the ages, has on the whole been put to enormous beneficial uses. Even greater opportunities lie ahead. Positive measures to enhance our opportunities to capitalize on our knowledge and on our talents can pay great dividends. An important role of government is to remove barriers and to speed progress in many fruitful areas.

Many agencies of government are now seeking ways to fulfill these roles—agencies in the Departments of Commerce, Interior, Agriculture, HUD, HEW, Transportation—and even the Department of Defense. The newly established Council on Urban Affairs, chaired and vigorously led by the President of the United States, is now seeking to enhance and coordinate these efforts in the field of urban problems. New Cabinet level mechanisms for doing the same in the general field of environmental studies and activities are now being developed. One of the chief tasks assigned to me as Science Adviser to the President is to recommend ways to use science and technology more extensively and more effectively to improve the quality of life for all Americans—and for people throughout the world.

I trust that the great American universities can assist in this endeavor. I hope they can invent innovative ways for organizing interdisciplinary programs for bringing our knowledge and our talents in science and social science to bear on the problems of our society.

Our government would be remiss if it did not seek out all the knowledge and talent that can be mustered. If we do not maintain a free society, we will have no free science and no free opportunity to develop and use its beneficial applications. We must continue to use to the maximum possible extent the resources of our science and engineering community in seeking solutions to the problems which endanger the health and welfare of our people.

These are the kinds of social control which we should all welcome.

Lack of Jobs - Not Food: New World Problem

HUNGER in the developing countries is no longer the greatest danger resulting from the population explosion, according to Keith Abercrombie, economist of the Food and Agriculture Organization of the United Nations. Employment problems in poor countries threaten to be more difficult to overcome than the lag in food production.

The rural areas of most developing countries will for a long time to come contain large numbers of farmers with little economic opportunity beyond the production of their own subsistence needs.

The persistence of such groups will be prolonged if rapid population growth continues, as well as by policies of concentrating scarce resources on more favored areas. Their difficulties will be increased as the extension of the agricultural area becomes less easy and the pressure of the agricultural population on the available land area increases.

Abercrombie suggests a number of actions that could help these groups:

- Recognize their existence, which has tended to be obscured in recent years by the urgent need to solve the short-run food supply problem as rapidly as possible.
- Use scarce capital resources to increase urban employment rather than to reduce rural employment.
- Take deliberate measures to increase alternative employment opportunities—part-time as well as full-time.

From: *Monthly Bulletin of Agricultural Economics and Statistics*
FAO, The United Nations
14:4, 1969

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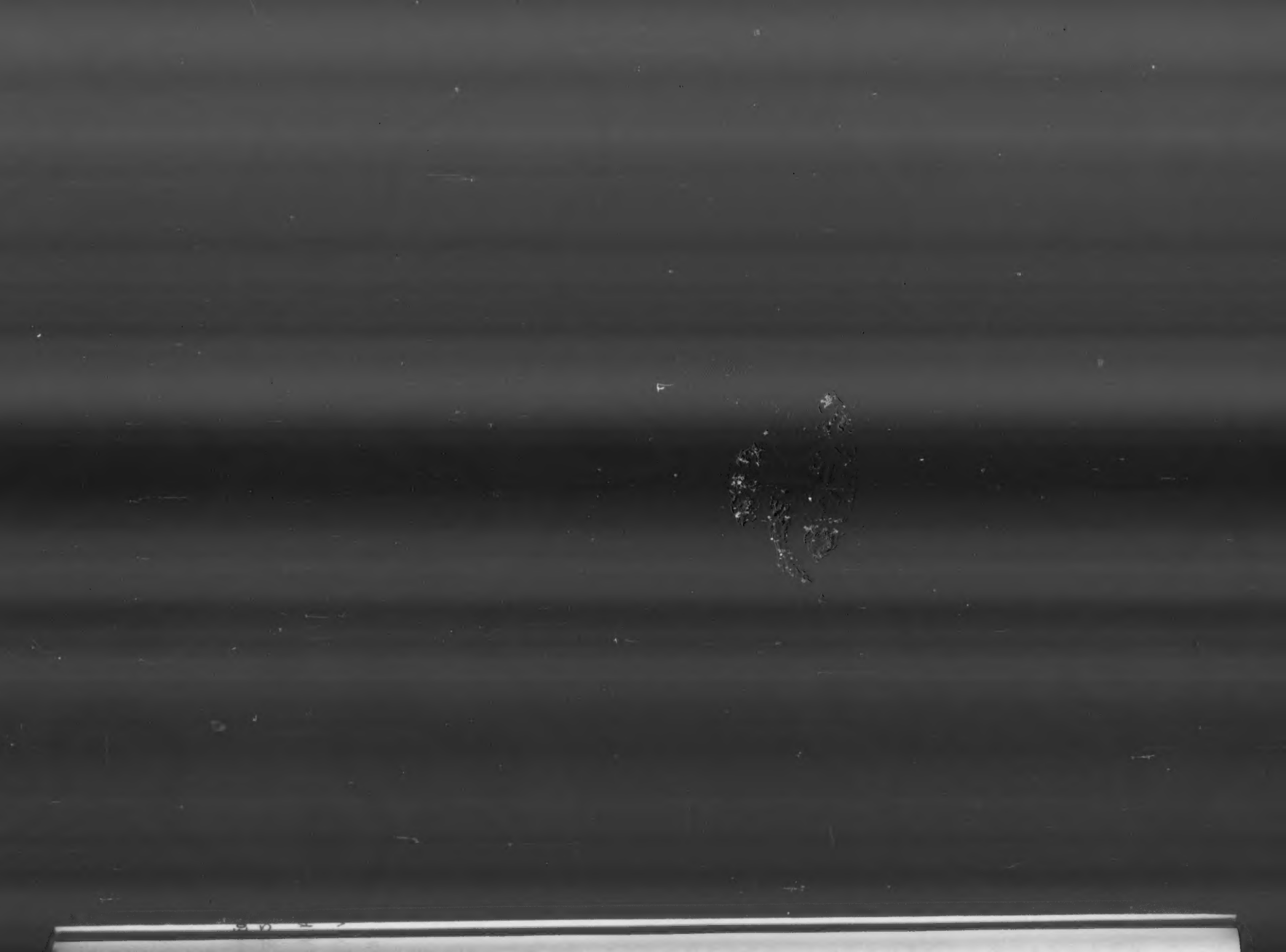
U.S. GOVERNMENT PRINTING OFFICE: 1969 O—350-869

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